CM-122
FINAL REPORT

"IMPOUNDMENT MANAGEMENT"
AND
"SEAGRASS MAPPING"

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PRINCIPAL INVESTIGATORS:

Douglas Carlson, IRMCD
Mosquito Production

G. Alan Curtis, IRMCD
Stastical Analysis

R. Grant Gilmore, HBOI
Fish and Macrocrustacean Studies

Jorge Rey, FMEL
Vegetation and Water Quality

Robert Virnstein, SEA
Seagrass Mapping

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INTRODUCTION

Enclosed are the final reports of the five principal investigators for CM 122. Carlson, Curtis, Gilmore, and Rey report on their work in impoundment 12, Indian River County. Virnstein provides his report and maps of seagrasses in the Indian River Lagoon, which was conducted as a separate project.

Dr. Virnstein's work is largely self-explanatory, and we provide no additional summary here, except to emphasize that this is the most complete record os seagrasses in the Indian River, and will serve as a standard referent for any future work on seagrass trends in this area.

The work in impoundment 12 culminates a series of NOAA/CZM funded studies which beginnning in 1982, designed to elucidate the impacts of various impoundment management strategies the flora and fauna found in the high marsh. This work has been performed in a 50 acre impounded high marsh in the Indian River lagoon under varying passive and active management regimes. At various periods during the last 4 years, the PIs have studied zooplankton, fish and macrocrustaceans, vegetation, water quality, and mosquito production. Depending on the parameter and particular study goal, sampling hs been performed twice-weekly (mosquitoes); twice-monthly (fish, macrocrustacean, water quality, zooplankton); and quarterly (vegetation cover and growth). All data has been filed on the data processing equipment of the respective institutions, and summaries of data sets are maintained on the local sponsoring agency's DP equipment (provided under CM 122 funding).

The PIs each make individual recommendations concerning future study topics, revised study methodologies, and impoundment management. Immediately following in this section are consensus summaries of these recommendations, and other observations by the PIs, which we (as the local sponsoring agency) wish to emphasize. Individual PIs may not agree in all respects with these summaries, but all have approved their inclusion. Note that most recommendations are tentative since they are based on data being collected up to the present, which obviously cannot be fully analyzed for some months to come.

IMPOUNDMENT MANAGEMENT RECOMMENDATIONS

Impoundment management recommendations are concerned primarily with opening and closing dates of culverts, and with culvert design, as these influence the use of the marsh by fish.

Culvert Closing Dates.

Impoundment closing dates (the date when culvert control structures are sealed and impoundment pumping begins) are usually set for April or May. Impoundment managers should be urged to refrain from pumping until forced to do so by tides or rainfall.

Further analysis of fish and tide data for the late May-early June period is required, but preliminary analysis indicates that a mid-June opening of the impoundment for several weeks may be of use -- especially if it is demonstrated that marsh transients who have over-wintered in the marsh or entered in early spring will exit the marsh during this period.

Opening Dates.

Analysis of fish populations in the marsh indicates that there is no serious conflict between the normal September or early October opening dates and use of the marsh by most marsh transients and residents. Readers interested in this topic should review Mr. Gilmore's section.

Work in this and prior years indicates some use of the open, impounded high marsh by fish during and immediately following the September high tide, and our preliminary recommendations have been that impoundments should be opened for this tide. However, analysis of seasonal tidal patterns, and observations of several fish kills in this and other areas, lead us to revise this recommendation.

Tidal histories for this area indicate that we can expect estuarine water levels to fall sharply after the first September high tide, resulting in large outflows from the open impoundment into the estuary. This may cause water quality problems in the adjacent estuary, and may also strand or concentrate fish in the perimeter ditch or in pools, providing high population densities, small water volume, very low DOs, and high temperatures. (We may note, though, that these same conditions are extremely advantageous for wading birds which prey on these fish.)

We urge that September opening dates NOT be locked into management proposals for Florida East Coast impoundments. October opening dates may offer a better trade-off of fish influx into the marsh versus fish kills in the marsh or estuary from water quality, population stress, or stranding.

Impoundment managers should be free to experiment on a site by site and season by season basis with opening schedules. Management plans should, however, require site inspections for fish kills after impoundment opening, with a special report submitted to the primary permitting/regulatory agency for each site.

Tides, culvert capacity, and the control of mosquitoes.

Agencies cannot make any generalizations about the use of tides to control mosquitoes or augment pumping. This can only be accomplished by studying the tidal amplitudes and frequencies on a site by site basis. The study area, for example, showed no monthly tidal cycle, and insufficient water levels to flood the marsh during the summer. Thus, use of additional culverts to provide tidal energy to flood the marsh would have been of no advantage in this marsh, at best eliminating perhaps 8 to 10 hours of pumping during the study period. Marshes several miles to the south, however, may well have benefited from tides as an augmentation to pumping during this same period. The only advantage additioan culvert capacity might offer in this site would be increased transport of fish to and from the marsh. This will be studied in the nest year.

It remains the local sponsoring agency's feeling that the rationales for high-volumes of culvert capacity need to be defined more clearly before large culvert capacity becomes a sine qua non in management plan approval. The PIs are continuing their studies of this question.

Control of mosquitoes in impoundments by fish.

Agencies should place no confidence in the ability of marsh resident or transient fish to control populations of mosquitoes. For the most part, Gambusia affinis, (the "mosquito fish") is found in low marsh areas while mosquitoes are found in the high marsh. Fish gut analysis showed relatively little predation on mosquito larvae. And even in those instances where Gambusia and Aedes larvae were seen in the same areas, the mosquito larvae persisted in high numbers to the pupal stage. Fish production as a component of mosquito control strategy in the impounded high marsh seems irrelevant.

Culvert construction.

Experience at this study site, in St. Lucie County, and elsewhere has shown that inadequate engineering has often been applied to the design and installation of the culvert and control structure. The primary problem is the degree of buoyancy inherent in flapgate/flapgate riser designs. Permitting agencies should ask that detailed consideration be given to ensure that culverts are placed securely enough to prevent the control-structure end from shifting upwards because of the continual floatation pressure from the water. Further, agencies should expect to have to re-set some culverts a year or two after initial installation, and should build these costs into their budgets.

Second, while it is possible to install a culvert at a uselessly high invert elevations (leaving it out of the water for long periods), it seems that a culvert cannot be placed too low for fish to enter and exit the marsh. Even normally surface dwelling fish such as *Gambusia* made use of a culvert with -2 ft invert, which was entirely submerged during most sampling periods. Thus, the limiting factors for culvert depth are the practical problems of river-bed and impoundment-bed elevations, not the swimming characteristics of marsh transient or resident fish.

Finally, there is strong evidence that snook and perhaps other fish are using the culverts as refuges prior to culvert opening. This attractant aspect of the culvert may be significant, and should be retained for now. Thus, for the present, we recommend that water control structures be placed on the inside of the impoundment, and the exterior culvert orifice be kept open so that it can be found and entereed by fish throughout the year.

Flooding elevations and vegetation.

One season of pumping and flooding to an elevation of 1 ft NGVD produced vegetation stress, but no massive vegetation kill. We will have no indication of the impact of flooding on vegetation until next winter and spring, when we see if seasonal species re-establish themselves. Work in this and other impoundments has also shown that it is impossible at this time to predict the set of vegetation which will re-populate a marsh (either in the near term or as the climax) when it is restored to the estuarine system.

Dr. Ray did comment, however, that provision should be made to restore impoundments to the target flooding level after unusual storm rains and tides. This design criteria should take at least 10 year storms into account. Impoundment managers should have contingency plans to achieve such water level reductions within a maximum of fourteen days, if severe stress on vegetation is to be avoided.

Flooding elevations and mosquitoes.

The flooding elevation of 1 ft. NGVD was the minimum which would cover mosquito breeding sites observed in previous studies. As expected, this elevation provided complete control of *Aedes taeniorhyncus* and *Aedes sollicitans*. The standing water, however, provided an opportunity for *Anopholine* mosquitoes to breed. These were apparently not controlled by fish, but never grew to sufficient numbers to represent an annoyance.

This aspect of the study simply re-confirms work performed a generation ago: impounding works. And it is the most effective mosquito control method which minimizes chemical applications. Only one chemical treatment was required this year during the management period, for the brood produced by the initial pumping. In previous years as many as 42 mosquito broods where observed over this impoundment during the May to October period.

AREAS OF SPECIAL INTEREST FOR FUTURE WORK

The PIs remain convinced that the most significantly changed aspect of the impounded marsh is the perimeter ditch. It provides refuge for predators which may cause abnormally high mortality on transients as they leave or enter the marsh; and it may encourage certain transients to remain in the marsh when they would otherwise leave it, and then cause significant mortality through low DOs or stranding.

The PIs agree that the following are significant areas of study in the internal perimeter ditch, characteristic of most impoundments:

Are there ways of getting fish out of the perimeter ditch in the spring, prior to closing?

Are there practical ways of raising DOs in portions of the perimeter ditch? And will this significantly help during the summer months?

What are the real impacts on the total populations of those species which may be lured into the perimeter ditch?

Additional work also needs to be done on the long term effects of summer pumping, fall tidal flooding, and winter dry-down on vegetation in the impoundment. These effects can only be determined over a number of years.

PROCEDURAL RECOMMENDATIONS

We became more aware this year of the difficulties of local government sponsorship of diverse, multi-agency research projects, and of the impact of low funding on obtaining useful management data from such projects.

We encountered some management difficulties with the seagrass project caused by the fact that it was a single project, funded to two separate agencies (IRMCD and Brevard County), with no central project manager. Thus there was no mechanism for resolving procedural differences. In fact, the project almost failed because management difficulties delayed obtaining aerial photographs.

As for the impoundment project, put at its simplest, we have overwhelmed ourselves with data. The addition of a statistician to the project for part of the year moved toward a unified view of the impoundment project, but could not (in the time available) provide anything approaching a coherent and complete synopsis. We are convinced that a multi-disciplinary approach is the only possible mode of achieving useful data for a complex ecological system -- but we also feel that the only way to utilize such data is to dedicate funding which allows the PIs to concentrate on data analysis, and which provides for at least one scientifically knowledgeable co-ordinator devoted to developing an over-view of the data.

We estimate we have at least one year of primary analysis remaining for certain data sets, in addition to data to be gathered from the same site in the coming year. Further analysis of the combined data sets may lag for several more years.

In retrospect, we feel we should have sought additional funding for combined project design and data analysis earlier. When only one team is working on one problem, this is not a concern. But if speedy procurement of management-related data is a primary objective, DER and the local sponsoring agencies should insist that multi-agency projects specifically provide for a unified approach. This is more expensive -- it may add another level of management between the local sponsoring agency and the various PIs -- but when possible, would yield better integrated, more complete recommendations in a far shorter time.

In part, we did not seek such additional funding because of the one-year nature of the funding. When we began this project, we had no idea how long we could continue work at this site. Thus, each year's work was, to a degree, a series of ad hoc studies, and there seemed no justification for a long-term data coordinator. Three or five year funding schedules would have provided more consistent data sets, and better correlations among data sets.

Longer-term funding is not merely desirable from a data-analysis perspective -- it is essential for ecological studies. One or two years of data on seasonal phenomena yields only one or two data points per parameter studied, and we can draw firm conclusions neither about populations nor about their trends from such numbers. Dr. Virnstein, for example, in this year's work on seagrass found unexpected abundance. Is this a sign of a robust estuarine system? Or is it an aberrant efflorescence, masking a trend of decline? A single year's work cannot pretend to address these questions -- and so can have no management implications. If CZM funding wishes to address long term estuarine management strategies, it should fund longer-term estuarine research projects.

ROTATIONAL MANAGEMENT IMPOUNDMENT AFFECTS ON FISH, MACROCRUSTACEAN AND AVIAN POPULATION DYNAMICS AND BASIC HYDROLOGICAL PARAMETERS

CM - 122

FINAL REPORT

R. Grant Gilmore and Dennis J. Peters

Harbor Branch Oceanographic Institution

5600 Old Dixie Highway

Fort Pierce, FL 33450

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INTRODUCTION

Historical research accounts of Impoundment 12, Indian River County, Florida, date from 1955 to the present. Throughout the 31 years of investigation, numerous researchers have implemented an array of sampling techniques in order to survey the flora, fishes, and invertebrates occurring in this marsh area. Nearly all of these studies were conducted as interdisciplinary research programs typically treating the interaction of mosquito populations or mosquito control strategies with the indigenous fauna and flora. A concise review of the past research efforts in Impoundment 12 will better elucidate the scientific developments of the present study.

The pioneer investigators, Harrington and colleagues, made their first ichthyofaunal collections over a three year period, 1955-1957, in an unimpounded marsh (site of Impoundment No. 12) inundated only by heavy rainfall or annual autumn tides (Harrington and Harrington, 1961). In 1966, a dike was constructed and the marsh site was impounded and managed by the Indian River Mosquito Control District as Impoundment No. 12. This salt marsh was again investigated by the Harringtons in 1968 in an effort to compare the food habits of fishes from Impoundment No. 12 with previous studies of the unimpounded salt marsh (Harrington and Harrington, 1961, 1982). During 1979, the impoundment was no longer managed and was kept closed, having no tidal connection with the adjacent estuary. It was at this time (1979-1980) that Gilmore made his first collections from the sites where Harrington and Harrington (1961) had made their collections (Gilmore et al., 1982). Comparisons of this data with data from a neighboring opened impoundment revealed the importance of tidal access to the immigration of marsh transient species.

From 1982 through 1984 (CZM-47 and CZM-73), Gilmore initiated one of the most intensive qualitative and quantitative studies of Impoundment 12 to be conducted along the east coast of Florida. Spatial, temporal, and diel distribution and migratory habits of fishes and macrocrustaceans throughout the marsh and adjacent estuary were studied (Gilmore, 1984). In addition, a comprehensive study of the trophic habits of the most abundant fishes was initiated. Due to the significance of this data, state, local, and private interests recognized the need for the continuation of the above research in order to accurately propose management strategies for similar impoundments of the area. Much of the information derived from this research was disseminated through professional presentations on local, state, regional and national levels.

From 1982 to present, the combined efforts of the Harbor Branch Oceanographic Institute (HBOI), the Florida Medical Entomology Laboratory (FMEL), and the Indian River Mosquito Control District (IRMCD) have engaged in a collaborative research investigation of Impoundment 12 (CZM-47, 1982-83; CZM-73, 1983-84; CZM-93, 1984-85; and CZM-122, 1985-86). During the 1984-85 CZM-93 research program, the marsh impoundment remained unmanaged, open to tidal inundation through two 45.7 cm diameter culverts separated by approximately one mile of dike road. As in the 1982-1984 (CZM-47 and CZM-73) study, fish and macrocrustacean distribution patterns relative to spatial and temporal parameters, fish population trophic analyses, and documentation of fish dispersal associated with marsh inundation were studied producing an extensive data base from which to compare future management scenerios. An important supplement to this study was a biweekly survey of the bird populations feeding in the impoundment.

During the past year, 1985-1986 (CZM 122), water levels in Impoundment 12 were managed by IRMCD to passively control mosquitos for the first time since 1978. Flapgates were installed on each of the culverts in late May and the impoundment was manually pumped. Inside impoundment water levels were maintained through September 16 at which time the flapgates were removed and the impoundment was again opened to tidal inundation. This management strategy is known as Rotational Impoundment Management (RIM) and now practiced by all counties with impounded marshes along the east coast of Florida (though with varying degrees of acreage under RIM management strategies). This year's sampling regime was an approximate duplication of the previous year's work. Special attention was focused on comparing the 'opened' period, May 21 - September 16, 1985 with the 'closed' period, May 21 - September 16, 1986. The primary objectives were to determine the effect of RIM on (1) major hydrological parameters and (2) fish, macrocrustacean, and avian spatial and temporal population dynamics. In addition to the CZM-93 data, an extensive historical data file from CZM-47 and CZM-73 can be used to further evaluate the effects of RIM on the indigenous wetland biota.

METHODOLOGY

Sampling equipment and intensities remained the same at all site locations as outlined in the CZM-93 final report. Culvert traps were simultaneously set for three hours in each culvert (stations 72 and 61) on each tide (4/24 hrs.). Replicate cast net throws were done at the 'mole hole' site (station 30). Additionally, day and night pull nets were taken adjacent to each culvert site (stations 71 and 60). Upper marsh sampling continued with ten throw net casts at each the 'low breed' (station 54) and 'high breed' (station 55) sites and a single heart trap set (24 hrs.) at the 'rain guage' site (station 56). Biweekly avifaunal observations resumed with supplimental counts taken from the dike road in addition to the counts taken from the bird blind.

Physical data was monitored at all sites each time a particular trap was set or sample was taken including; temperature, dissolved oxygen, salinity, and pH. Continuous water level recordings were taken from inside and outside the impoundment at station 61 near the south culvert. Several months of upper marsh (station P3) water level data was taken just prior to the flapgate installation.

RESULTS

A. Physical parameters.

Figures 1 - 6 present the mean values for various physical parameters at specific locations and in broad regions of the marsh on the day of faunal collections. The annual mean of the respective parameter is also given.

The mean marsh elevation, approximately 16.9 cm, is nearly equal to the mean annual water level, 16.5 cm, recorded from September 1984 to August 1986. Therefore, the plot of mean water level in the figures approximates the mean surface elevation of the marsh and the inundation of the marsh can be predicted from the water level plots over time (Fig.s 1 -6). In the unmanaged marsh, 1984-85, the marsh surface was infrequently inundated from December through September. This means that the majority of the marsh surface was not available to the aquatic fauna for nine months of the year when the marsh was open to tidal influence. Under RIM, spring/summer 1986, the marsh surface was artificially flooded on 21 May, over three months before the natural seasonal late summer/fall inundation observed during the preceding two years, 1984, 1985. Flapgates were left in place from 21 May to 16 September. As impoundment water levels during this period exceeded the estuarine high tide amplitudes the flapgates did not open to allow estuarine water to enter the impoundment until early September. Therefore,the impoundment was effectively isolated from the open estuary during the RIM spring/summer control period, which in this case was 119 days.

The pH of the impoundment waters showed both spatial and temporal variations. The upper marsh flats had the highest pH values while the perimeter ditch (lower marsh) had the lowest (Fig. 1, 2). The culvert sites had an intermediate mean pH level between the perimeter ditch and upper marsh (Fig. 3, 4). Seasonal patterns are complicated by the malfunction of several pH meters used throughout the study period, therefore producing missing values during, October 1984, 1985, December 1985, January and March 1986. The most consistent seasonal phenomena is the general increase in pH during the summer months, particularly during RIM. The minimum pH values were recorded during the fall, October and December and during the spring, April - May.

Dissolved oxygen values showed significant spatial and temporal differences. Nearly all D.O. values from the upper marsh were above the mean for the impoundment (Fig. 1). The lower marsh D.O. values were lowest within the perimeter ditch (Fig. 5, 6), somewhat higher at the culvert sites (Fig. 3,4). Dissolved oxygen reaches its seasonal low during the summer at all locations and was lower during RIM than in the preceding year, particularly within the perimeter ditch at station 71 (Fig. 5).

Salinities were highest on the upper marsh (Fig. 1), most moderate at the culvert sites (Fig. 3,4). The most hypersaline conditions were reached on the upper marsh during the RIM closure period, i.e. 53 ppt.

Water temperatures also reached their highest levels during RIM on the upper marsh, i.e. mean temperature of 29.9 C. Temperatures and salinities were most moderate at the culvert sites (Fig. 3,4). The lowest seasonal temperatures were observed within the perimeter ditch, 2.0 C (Fig. 5,6).

B. Community Composition

A total of 33 fish and 6 decapod crustacean species were collected between October 1984 and September 1986 in Impoundment 12 (CZM - 93 + CZM - 122; Table 1). During the summer with tidal access 19 fish and 4 crustacean species were collected, while during RIM the summer collections were limited to 12 fish and 2 crustacean species. The species composition of the impoundment fauna was reduced 40% by RIM, the total number of individuals by 31%. The resident species collections most significantly affected by impoundment closure was Palaemonetes spp. and the Gulf killifish, Fundulus grandis, both of which dropped to 0 individuals captured from the preceding summer's collection of 1,693 and 63, respectively. Other collections were also affected negatively, i.e. marsh killifish, Fundulus confluentus, sheepshead minnow, Cyprinodon variegatus and the sailfin molly, Poecilia latipinna, with population drops of from 535 to 19, 10,310 to 1,976 and 9,396 to 3,675, respectively. These reduced captures may not be due to actual reduced numbers of individuals due to increased available habitat and dispersal from the standard collection sites as will be discussed below. The only resident species increasing in number collected were the mosquitofish, Gambusia affinis, with from 1,339 to 8,985, and the inland silverside, Menidia beryllina, increasing from 166 to 811.

Transient species were most greatly affected with only 8 of the 28 recorded during 1984-86 collected during the impoundment closure period, 8 of 14 recorded from the preceding summer under tidal influence (Table 1). Yet except for the ladyfish, Elops saurus, which dove from 247 to 0 individuals collected, the numerical reductions were not significant as the summer period is not considered a major transient recruitment period. The striped mullet, Mugil cephalus, actually increased in numbers captured, from 55 to 398. It is anticipated that many of the transient species collected during RIM were in the impoundment before its closure and were subsequently trapped and captured later during the summer.

Twenty-eight avian species, 6,267 individuals, were counted within the impoundment from October 1984 to September 1986 (Table 2). A total of 23 during CM-93, 24 during CM - 122. Except for significant increases in wood storks (21 to 203), belted kingfishers (13 to 31) and green-backed herons (12 to 54) counts, and decreases in tricolored herons (167 to 95), little blue herons (151 to 88), ospreys (136 to 97) and double-crested cormorants (47 to 6) the species rankings based on number of individuals changed little between the years. No major species changes took place during the RIM period, except for the increase in great egret counts from 0 to 44 and red-bellied woodpecker, an anhinga and a black skimmer were observed for the first time during the summer months.

C. Temporal/ Spatial Dynamics

The major spatial regions of the marsh to be considered in this analysis are the culvert sites, stations 61 and 72, perimeter ditch sites, stations 60 and 71, and the upper marsh sites, stations 54, 55 and 56. Faunal density estimates are based only on stations 54, 55, 60 and 71. Stations 54, 55 and 56 are considered upper marsh, while stations 60, 61, 71 and 72 are considered lower marsh.

Figures 7, 8, 9 and 10 present the biweekly distribution of all collections and transient/resident species between the upper and lower marsh. Fish densities were comparable between the habitats, though generally higher in the perimeter ditch (Fig. 7). The densities were highest on the upper marsh when they were lowest in the perimeter ditch, principally during the fall. Fish presence on the upper marsh corresponds with the seasonal inundation of that habitat both under natural conditions, during the fall, or artificial conditions during the summer of 1986 in RIM (Fig.s 7 and 8). Transient species populations were lowest during the summer in both the tidal year, 1985 and the RIM year, 1986 (Fig. 9). Transient use of the upper marsh was minimal even during seasonal fall inundations (Fig. 10). Resident use of the upper marsh was heaviest during the fall inundation, but also obvious during RIM. Resident populations reached their peak during the winter sea level recession, particularly during year one, 1984-1985. Transient species also reached their population peak during this period.

The three most abundant transient species were the striped and white mullets and the ladyfish. All show similar patterns in population dynamicswith no captures on the upper marsh flats and minimum population levels in occurring in the marsh during the summer (Figures 11,12, 13). Striped mullet populations reached peak seasonal abundance in the marsh during the winter and spring, white mullet during the fall and late spring. Ladyfish were most abundant both years during the fall and spring with limited summer recruitment which was nearly completely stopped during the RIM months.

Spatial and temporal population dynamics of the three most abundant resident species, the sheepshead minnow, sailfin molly and the mosquitofish are presented in figures 14, 15 and 16. Densities of sheepshead minnows frequently reached level at or above 10 fish per m^2 between December and April/May (Fig. 14). After a summer population low in the perimeter ditch the densities began to increase August and September until the upper marsh was inundated during the fall at which time the dispersal of sheepshead minnow across the upper marsh reduced perimeter ditch densities. During RIM the sheepshead minnow dispersed across the upper marsh. This species is the only species to be found on the upper marsh during the summer of 1985, prior to RIM. The sailfin molly revealed a quite similar pattern (Fig. 15). However, the mosquitofish did not show the same level of density declines in the perimeter ditch during either fall inundations or during RIM upper marsh inundations. Mosquitofish populations actually increased in the perimeter ditch during RIM and their use of the upper marsh flats was significantly less than the sheepshead minnow and sailfin molly.

Palaemonid shrimp were totally absent from collections made during RIM. Their capture was principally most successful in the culvert traps. Culvert trap collections were significantly reduced during RIM due to the absence of water flow through the culvert. This pattern was also observed for penaeid shrimp and portunid crabs. All of these crustaceans are most abundant in fall to spring collections whether under tidal influence or not, however, palaemonid shrimp are most significantly impacted by RIM.

Bird populations showed great variation in individual species counts and total annual count patterns. This is typical of mobile widely ranging bird species, such as the wading birds which numerically dominate the avifauna. A comparison between the CZM-93, 1984-85, total counts and and the CZM-122, 1985-86, total counts for the biweekly periods reveals this variation (Fig. 17). The primary analogous seasonal patterns observed between the two years are the January/February peak associated with the winter sea level recession and concentration of fishes in the lower marsh. A similar peak was observed in April/May also associated with a sea level recession. Wading bird use of the marsh was somewhat elevated during RIM but not significantly so.

Individual species revealed great variation in seasonal use of impoundment 12. This variation can be seen in white ibis, snowy egret and great egret population pattern revealed in figure 18. There is a general fall and winter peak in all three species, a spring peak in snowy and great egrets. White ibis populations reached a seasonal low during the spring and early summer. The only species of the three to show an obvious positive reaction to RIM was the great egret.

Two endangered wading bird species that utilized the marsh in significant numbers were the roseate spoonbill and wood stork. Roseate spoonbills were present in the marsh both during RIM and during the tidal access period with principally a consistent summer use. However, spoonbills were observed during the winter months the second year but not during the first year of study, indicating that their may be considerable population variations between years. The wood stork use of impoundment 12 is principally limited to the fall and winter months with increased use during the second year.

Avian spacial distribution patterns within the marsh observed during RIM revealed an increased use of the south and north quadrats during RIM over the previous years observations.

DISCUSSION

The overall objective of the CZM - 122 research program was to determine the affects of a Rotational Impoundment Management program on the impounded marsh ecosystem. These affects were to be determined based on several years of historical study of this particular marsh and impoundment (Harrington and Harrington 1961, 1982; Gilmore et al. 1982; CZM - 47, CZM - 73 and CZM - 93). Our knowledge of this ecosystem has progressed to the point that some conclusions and recommendations can be made relative to indigenous fish, decapod and avian populations.

A. Water Level Management Affects

The positive aspects of water level management are complex enough at our present level of analyses to allow only conjectural statements to made. There is little question that resident fish and crustacean populations are permitted to utilize the upper marsh surface for a longer period of time. These organisms disperse over nearly the entire marsh surface. The most abundant fish species, the sheepshead minnow, forms territories for mating and feeding across the marsh. Their densities on the upper marsh typically varying from 0.1 to 5.0 per m^2 with alternating high and low densities on a four week cycle. The densities during RIM were similar to those observed during the fall inundation. This observation further demonstrates that this species is territorial with some optimum density across the upper marsh flats. The sailfin molly and mosquito are also commonly captured on the upper marsh but are not territorial. These latter species show significant variation between the fall inundation habitation of the upper marsh and the RIM period. These observations suggest that their is a carrying capacity or limitation on the number of fish that can occupy the upper marsh flats, particularly concerning the most abundant and territorial sheepshead minnows. Therefore, the time at which this carrying capacity is reached is critical when comparing RIM with natural fall inundations. Figure 4 indicates that it is reached within the first few weeks of marsh inundation. The longevity of sheepshead minnows without predation is such that the same fish could survive throughout the RIM and fall inundation period, i.e. 6 to 7 months. Therefore, if no predation occurs the turnover of individuals would be low, larval and juvenile mortality high (to territorial adults). This would in turn mean that longer flood periods would not export additional protein from the upper marsh to the lower marsh or estuary than would a typical fall inundation period of 2 - 3 months. The only way it would is if piscivorous birds and fish could consume more sheepshead minnows during the RIM period. With increased consumption sheepshead minnows there would be increased turnover per unit time and with a longer inundation period more export of biomass (in the form of consumed sheepshead minnows) from the upper marsh. However, there is no indication that predator consumption of sheepshead minnows increases during the RIM period, particularly as the estuarine access to the marsh is closed and wading use of the impounded marsh is not great during the summer RIM period. It is quite possible that the reduction in piscivorous predators during RIM may have had a positive affect on mosquitofish populations within the perimeter ditch allowing the observed rapid increase in their numbers.

A negative aspect of water management is the decreased populations of certain marsh residents which depend on periodic marsh exposure for effective reproduction. Major examples are the marsh killifish, _Fundulus confluentus_ and the Gulf killifish, _F_. _grandis_. Both declined significantly during RIM and were also found to be eradicated by impoundment closure in previous studies (Gilmore et al. 1982).

B. Impoundment Closure Affects

Impoundment closure has been found to effectively stop transient fish and crustacean migration between the estuary and the impounded marsh. Those species which due make tidal migrations into the impoundment during the summer months typically had populations reduced to 0 during RIM (i.e. ladyfish and palaemonid shrimp). An exception was the increased catch of white mullet during RIM over the preceding annual catch under tidal conditions. This closure would also limit resident fish migration to the adjacent estuary.

Closure also does not permit the emigration of fishes from the impoundment during periods of physiological stress. The summer months are the period of greatest hypoxic stress and we have recorded fish mortalities during this period in closed systems (Gilmore et al. 1985).

A positive aspect of closure may be the reduced predation on mosquitofish as mentioned above. As mosquitofish are not territorial they may be able to reproduce in significant enough numbers free of major predatory mortalities and therefore allow a larger standing crop to develop prior to the opening of impoundment. The fate of this standing crop after the impoundment is opened to tidal influence is open to speculation. The mosquitofish may migrate into the estuary and subsequently be consumed in another habitat or they may be consumed within the impoundment as piscivorous fishes and birds reach their peak populations for fall through spring. In either case the production of fish and subsequent export of this production from the salt marsh to other ecosystem will have increased.

Management Improvements - Water Level Control

The maintenance of a water level at a desired height is both necessary for adequate mosquito control and preservation of the indigenous vegetation. It also allows fish access to the upper marsh flats. The significance of this latter consideration is not yet determined so it is difficult to maintain that water levels promote fish, crustacean and avian use of the impounded upper marsh plain and increase resident populations and biological export over beyond the levels typical of the fall sea level inundation.

There has been some difficulty in setting control structures for water level control. Control of culvert elevation has been most difficult. Therefore, there should be some allowance for this variation within the design of the flapgate and weir structure fitted to the end of the culvert that actually controls the managed water height. The north culvert at site 71 was not functional in water height management due to the floatation of the inside end of the culvert. As the weir structure only covers the upper end of the water control assembly it was not effective in allowing water release. This could be effectively modified in two ways: (1) Attach a flapgate weir in which the entire structure is a weir which can be easily modified by pulling riser boards, or (2) set the culvert elevation at lower levels and brace during the initial set, which will insure a lower elevation for the weir structure which is at the top of the water control assembly.

There is some hypothetical argument for the placement of the water control assembly on the impoundment side of the culvert. This would allow the fish queing on water release, which is now thought to occur in snook, to aggregate in a protected environment within the culvert rather than along the estuarine edge outside of the culvert where predation pressure by larger fish can be quite intense.

Management Improvements Impoundment - Estuarine Access

The initial closure of the impoundment is critical in that several transient species can be captured in the impoundment without the ability to egress until the fall inundation. This in effect means that they will have to survive the most anoxic period of the year, the summer, in the perimeter ditch habitat. Periodic fish kills have been observed at other sites during this period and nearly all of the fishes suffering hypoxia were transient species. For this reason it would be quite beneficial to develop and test a mechanism for controlling impoundment water levels and yet allow or induce transient fish emigration from the impoundment. I suggest that serious consideration be given to this problem or RIM impoundment management strategies could in effect be blamed for trapping and killing fishery species during a critical period in their life histories.

A mid-summer dry down of the impoundment is another possible access improvement that may be examined under experimental conditions. This would allow transient fish egress during a period in which typically leave the confines of the marsh. The possible affects on mosquito oviposition must be considered, but the July low in sea level and low dissolved oxygen conditions within the impoundment would allow an opening at this time to flush the perimeter ditch without flooding the principal breeding areas on the upper marsh. Rainfall would. There is also the possibility that a release of anoxic water from the perimeter ditch could also produce a fish kill in the adjacent estuary which has now been documented at other sites.

Conclusion

The present RIM program is basically compatible with the migratory habits of the principal organisms utilizing the marsh. The impoundment closure comes during a period in which most transient species do not utilize the regional salt marsh habitat. The artificial inundation during the summer is deleterious to some marsh residents but also allows other residents to take an advantage of the increased availability of the marsh flats for both spawning and feeding. Avian use has only been seen to increase significantly in one species, the great egret, but no overall deleterious effects have been seen in avian populations due to RIM. This is only the initial evaluation of the Rotational Impoundment Management program and we strongly suggest that there be further study of both standard management practices and modified management under experimental conditions. These results are preliminary.

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ACKNOWLEDGEMENTS

Mr. Peter O'Bryan of IRMCD aided with field collections and laboratory treatment of specimens. Mr. Peter Hood, Ben McLaughlin, Derek Tremain, Doug Scheidt and Ron Brockmeyer of HBOI aided with various aspects of field and laboratory activities.

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Table 1. Species list of fishes and macrocrustaceans collected in Impoundment No. 12 from September 1984 through August 1986. Tabulations represent a comparison of the total number of individuals collected from all sites during each year of the study periods, the opened management periods, and the closed management periods.

Fish and Macrocrustaceans Ranked by Abundance	Total Study Period October 1984 - September 1986 CM93 84-85	CM122 85-86	CM93+CM122 84-86	Open Management Period October - May CM93 84-85	CM122 85-86	Closed Management Period June - September CM93 84-85	CM122 85-86
Cyprinodon variegatus	83579	28020	111599	58452	26044	10310	1976
Poecilia latipinna	39640	20884	60524	13710	17209	9396	3675
Gambusia affinis	20707	20834	41541	13846	11849	1339	8985
Palaemonetes spp	10644	5321	15965	8761	5187	1693	0
Fundulus confluentus	3374	803	4177	2775	720	535	19
Mugil cephalus	2732	6727	9459	2663	6708	55	398
Mugil curema	1297	485	1782	1189	87	103	241
Menidia beryllina	1184	2703	3887	992	2462	166	811
Elops saurus	951	2075	3026	679	1264	247	0
Centropomus undecimalis	664	814	1478	625	814	12	0
Gerres cinereus	199	46	245	193	46	1	
Fundulus grandis	132	913	1045	28	755	63	0
Penaeus spp	111	71	182	99	70	8	1
Lucania parva	71	34	105	15	28	7	6
Callinectes spp	57	15	72	36	15	14	0
Eucinostomus harengulus	48	0	48	48	0	0	0
Gobiosoma robustum	41	1	42	40	1	1	0
Diapterus auratus	15	0	15	15	0	0	0
Brevoortia spp	14	14	28	14	14	0	0
Syngnathus scovelli	7	11	18	3	11	4	0
Lutjanus griseus	7	3	10	1	2	3	1
Eucinostomus argenteus	6	1	7	6	1	0	0
Anguilla rostrata	5	1	6	5	1	0	0
Gobiosoma bosci	5	0	5	5	0	0	0
Alpheus armillatus	4	1	5	3	1	0	0
Ara spp	3	1	4	0	1	3	0
Lagodon rhomboides	3	4	7	2	4	1	0
Pogonias cromis	3	52	55	2	43	1	9
Uca spp	3	13	16	3	1	0	12
Harengula jaguana	3	0	3	3	0	0	0
Microgobius gulosus	3	0	3	3	0	0	6
Dormitator maculatus	2	6	8	2	0	0	0
Eucinostomus gula	2	0	2	2	2	0	0
Leiostomus xanthurus	2	2	4	2	2	0	0

Trachinotus falcatus	2	0	2	2	0	0	0
Achirus lineatus	1	0	1	0	0	1	0
Fundulus similis	1	3	4	0	2	1	1
Hippocampus zosterae	1	1	2	1	1	0	0
Sphyraena barracuda	1	0	1	1	1	0	0
Totals	165524	89875	255399	104226	73356	23964	16519

Table 2. A species list of the avifauna observed in Impoundment No. 12 from September 1984 through August 1986. Tabulations represent a comparison of the total number of individuals observed over the entire impoundment during each year of the study periods, the opened management periods, and the closed management periods.

Avian Species	Total Study Period October 1984 - September 1986			Open Management Period October - May		Closed Management Period June - September	
	CM93	CM122	CM93+CM122	CM93	CM122	CM93	CM122
Ranked By Abundance	84-85	85-86	84-86	84-85	85-86	84-85	85-86
White Ibis	1370	1618	2988	1145	1464	245	154
Snowy Egret	311	411	722	220	305	91	106
Least Sandpiper	326	243	569	326	243	0	0
Great Egret	209	227	436	209	183	0	44
Tricolored Heron	167	95	262	135	67	32	28
Little Blue Heron	151	88	239	122	64	29	24
Osprey	136	97	233	118	75	18	22
Wood Stork	21	203	224	21	203	0	0
Roseate Spoonbill	69	86	155	31	63	38	23
Great Blue Heron	35	41	76	28	25	7	16
Brown Pelican	37	32	69	37	32	0	0
Green-backed Heron	12	54	66	9	30	3	24
Fish Crow	40	26	66	38	18	4	8
Double-crested Cormorant	47	6	53	47	6	0	0
Belted Kingfisher	13	31	44	12	24	1	7
Red-bellied Woodpecker	1	18	19	1	15	0	3
Pileated Woodpecker	12	0	12	12	0	0	0
Mottled Duck	0	7	7	0	7	0	0
Ring-billed Gull	6	0	6	6	0	0	0
Turkey Vulture	2	3	5	2	3	0	0
Black Bird	4	0	4	4	0	0	0
Anhinga	1	2	3	1	1	0	1
Black-crowned Night Heron	1	1	2	0	1	1	0
Semipalmated Plover	0	2	2	0	2	0	0
Common Ground Dove	2	0	2	2	0	0	0
Screech-Owl	0	1	1	0	1	0	0
Black Skimmer	0	1	1	0	0	0	1
Red-shouldered Hawk	0	1	1	0	1	0	0
Totals: 28 Species	2973	3294	6267	2504	2823	469	471

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Figure 6. Physical data comparisons of temperature, salinity, dissolved oxygen, pH, and inside impoundment water level for pull net station 60 of Impoundment No. 12 from September 1984 through August 1986.

Figure 6. Physical data comparisons of temperature, salinity, dissolved oxygen, pH, and inside impoundment water level for pull net station 60 of Impoundment No. 12 from September 1984 through August 1986.

Figure 7. Upper and lower marsh density (number per meter squared) comparisons of fish and macrocrustaceans collected in Impoundment No. 12 from September 1984 through August 1986. Closed management period for 1986 is indicated by asterisks.

Figure 8. Comparison of total number of fish and macrocrustaceans collected from the upper and lower marsh of Impoundment No. 12 from September 1984 through August 1986. Closed management period for 1986 is indicated by asterisks.

Figure 9. Total marsh comparisons of the total number of resident and transient fishes and macrocrustaceans collected in Impoundment No. 12 from September 1984 through August 1986. Closed management period for 1986 is indicated by asterisks.

Figure 10. Upper and lower marsh comparisons of the total number of resident and transient fishes and macrocrustaceans collected in Impoundment No. 12 from September 1984 through August 1986. Closed management period for 1986 is indicated by asterisks.

Figure 11. Upper and lower marsh density (number per meter squared) comparisons for _Mugil cephalus_ collected in Impoundment No. 12 from September 1984 through August 1986. Closed management period for 1986 is indicated by asterisks.

Figure 12. Upper and lower marsh density (number per meter squared) comparisons for _Mugil curema_ collected in Impoundment No. 12 from September 1984 through August 1986. Closed management period for 1986 is indicated by asterisks.

Figure 13. Upper and lower marsh density (number per meter squared) comparisons for _Elops saurus_ collected in Impoundment No. 12 from September 1984 through August 1986. Closed management period for 1986 is indicated by asterisks.

Figure 14. Upper and lower marsh density (number per meter squared) comparisons for _Cyprinodon variegatus_ collected in Impoundment No. 12 from September 1984 through August 1986. Closed management period for 1986 is indicated by asterisks.

Figure 15. Upper and lower marsh density (number per meter squared) comparisons for Poecilia latipinna collected in Impoundment No. 12 from September 1984 through August 1986. Closed management period for 1986 is indicated by asterisks.

Figure 16. Upper and lower marsh density (number per meter squared) comparisons for Gambusia affinis collected in Impoundment No. 12 from September 1984 through August 1986. Closed management period for 1986 is indicated by asterisks.

Figure 17. Yearly and total study comparisons of the total number of birds observed in Impoundment No. 12 from September 1984 through August 1986. Closed management period for 1986 is indicated by asterisks.

Figure 18. Comparison of the total number of White Ibis, Snowy Egrets, and great Egrets observed in Impoundment No. 12 from September 1984 through August 1986. Closed management period for 1986 is indicated by asterisks.

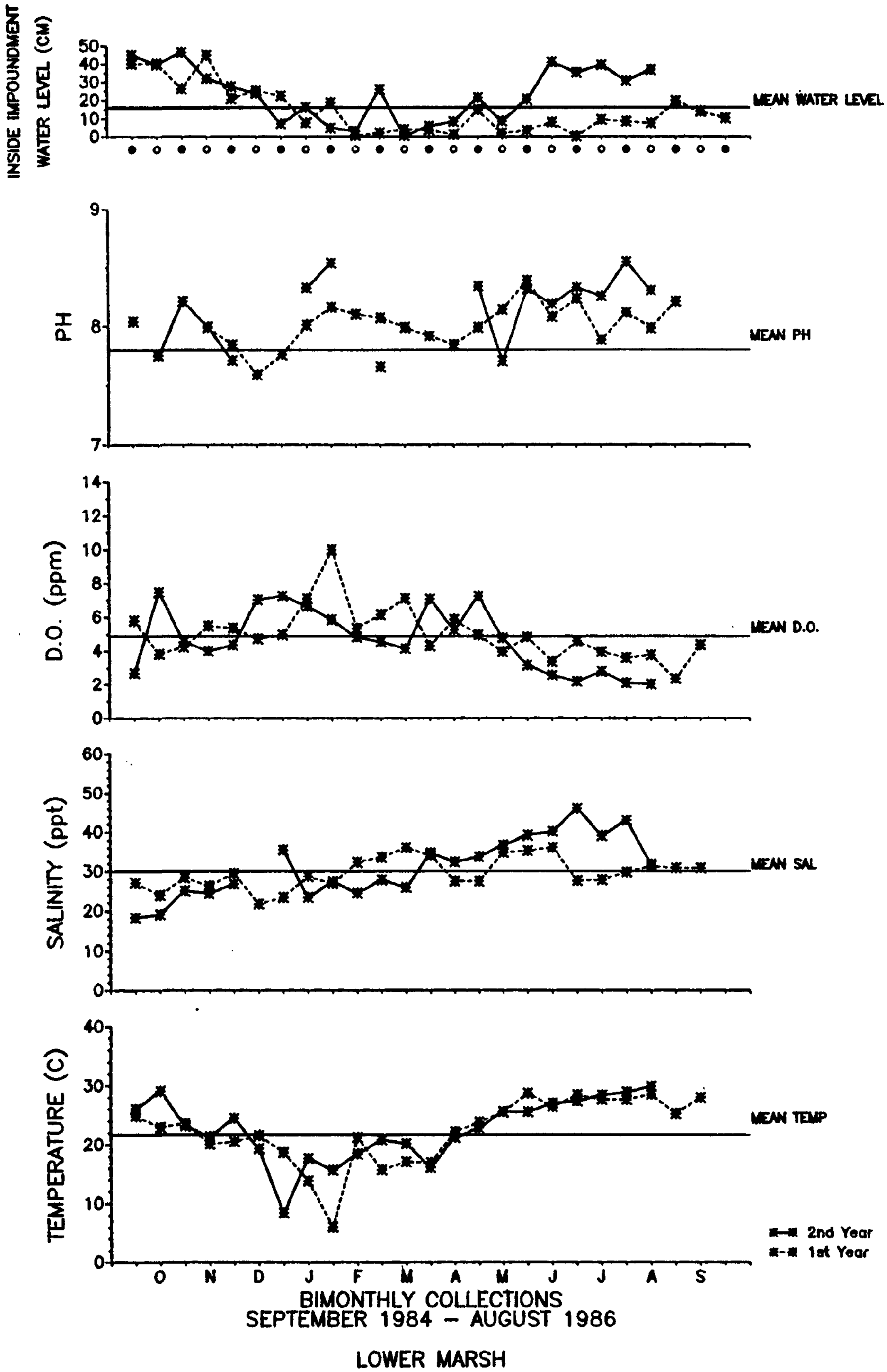
Figure 19. Comparison of the total number of Wood Storks and Roseate Spoonbills observed in Impoundment No. 12 from September 1984 through August 1986. Closed management period for 1986 is indicated by asterisks.

Figure 20. Comparison of the total number of birds observed during the opened and closed management periods from the south, central, and north

Figure 20. Comparison of the total number of birds observed during the opened and closed management periods from the south, central, and north quads of Impoundment No. 12 from September 1984 through August 1986. Closed management period for 1986 is indicated by asterisks.

Figure 21. Comparison of the total number of resident and transient fishes and macrocrustaceans and birds observed in Impoundment No. 12 from September 1984 through August 1986. Closed management period for 1986 is indicated by asterisks.

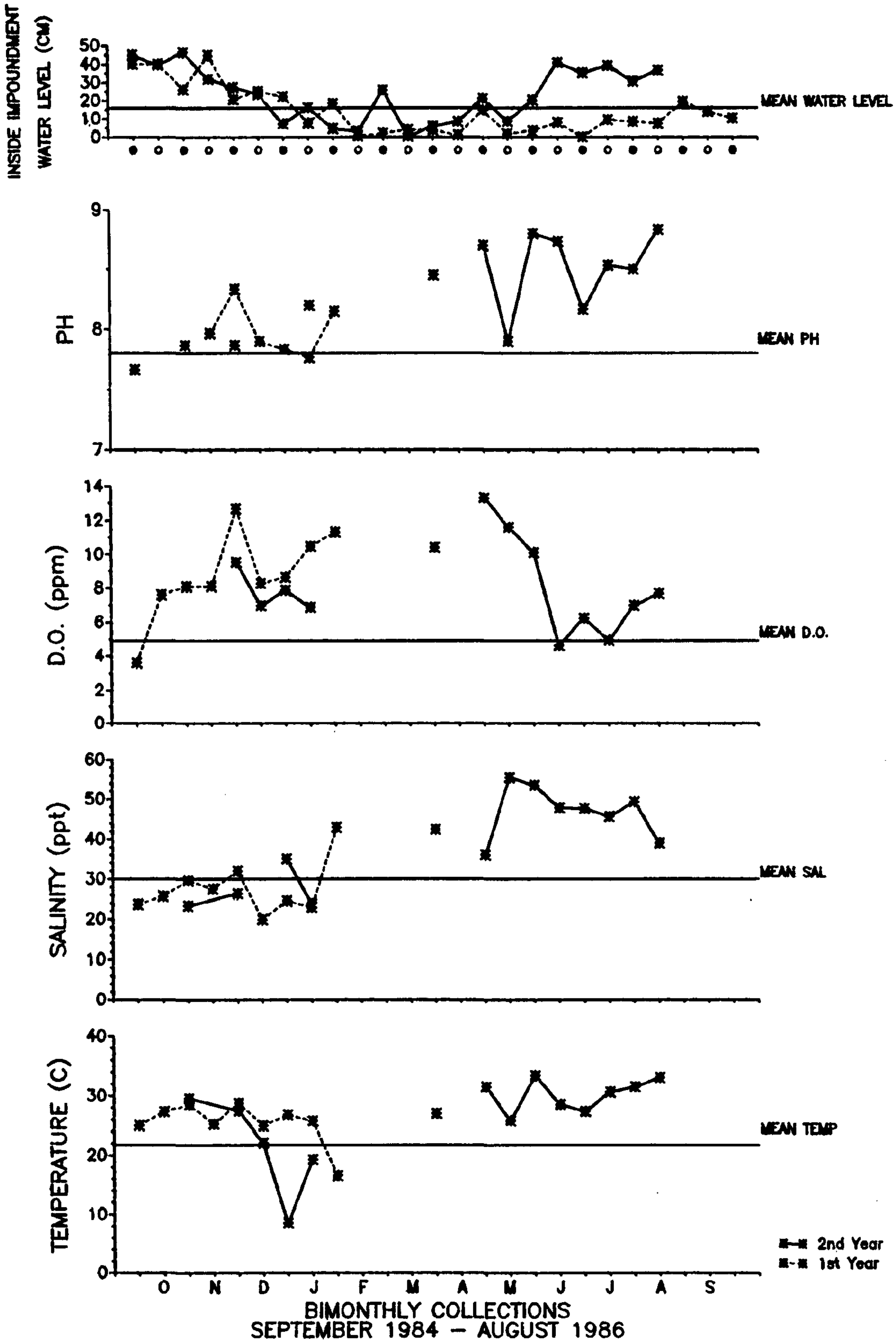
Figure 1. Physical data comparisons of temperature, salinity, dissolved oxygen, pH, and inside impoundment water level for the combined lower marsh sites (stations 60, 61, 71, 72) of Impoundment No. 12 from September 1984 through August 1986.



INSIDE IMPOUNDMENT WATER LEVEL (CM)
MEAN WATER LEVEL
PH
MEAN PH
D.O. (ppm)
MEAN D.O.
SALINITY (ppt)
MEAN SAL
TEMPERATURE (C)
MEAN TEMP
2nd Year
1st Year
O N D J F M A M J J A S
BIMONTHLY COLLECTIONS
SEPTEMBER 1984 – AUGUST 1986
LOWER MARSH

Figure 1.

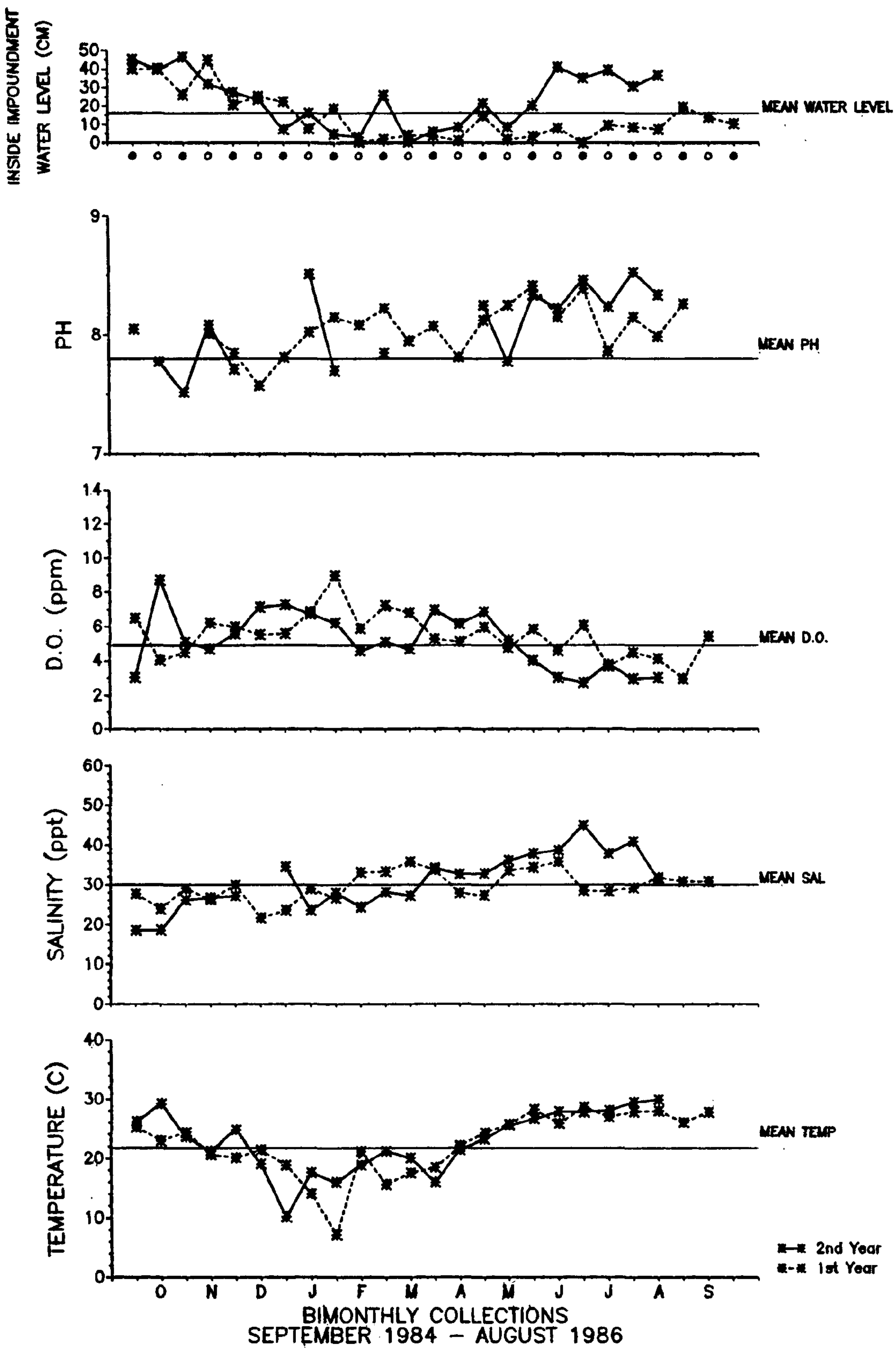
Figure 2. Physical data comparisons of temperature, salinity, dissolved oxygen, pH, and inside impoundment water level for the combined upper marsh sites (stations 54, 55, 56) of Impoundment No. 12 from September 1984 through August 1986.



UPPER MARSH

Figure 2.

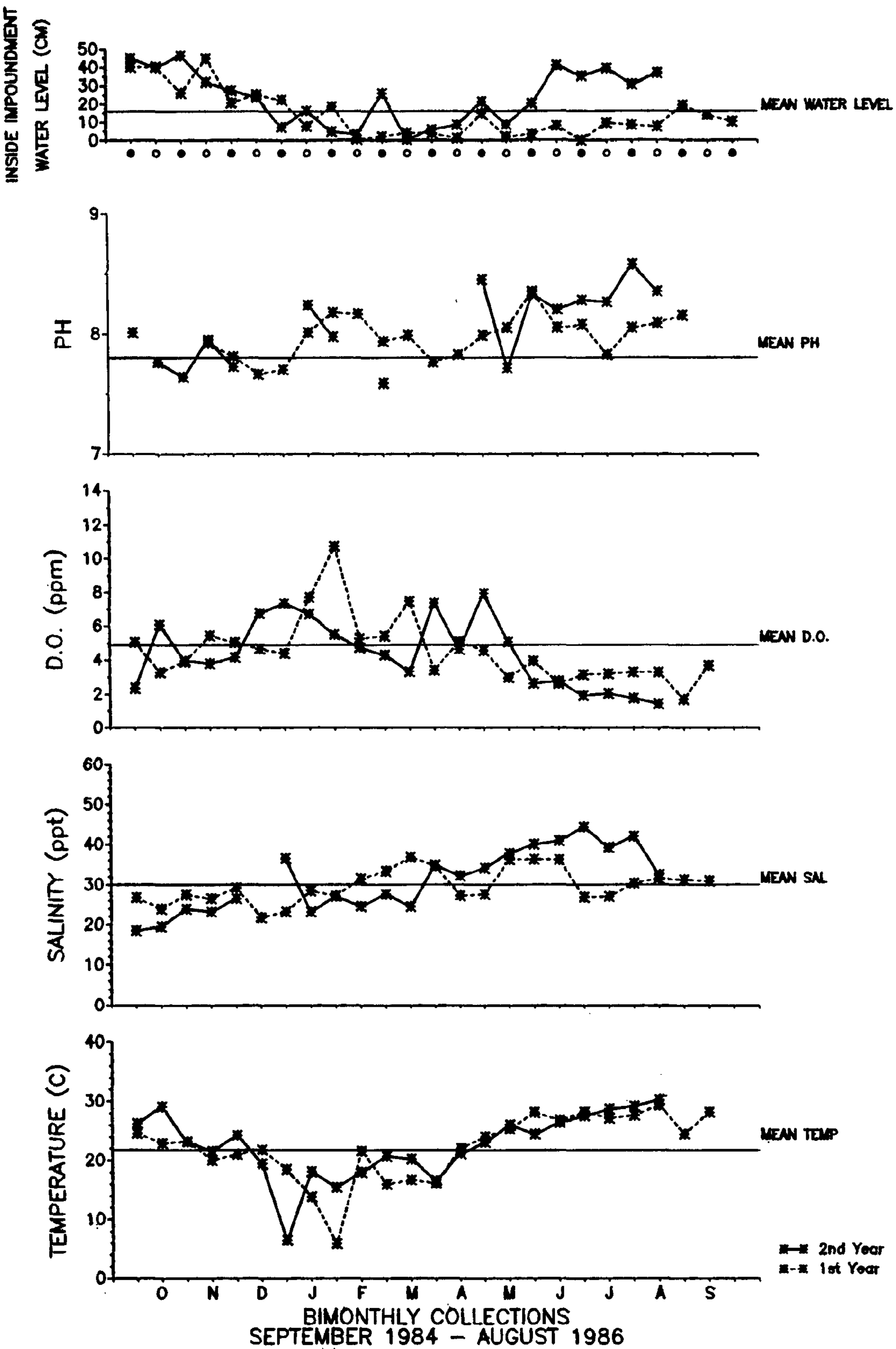
Figure 3. Physical data comparisons of temperature, salinity, dissolved oxygen, pH, and inside impoundment water level for culvert station 72 of Impoundment No. 12 from September 1984 through August 1986.



STATION 72

Figure 3.

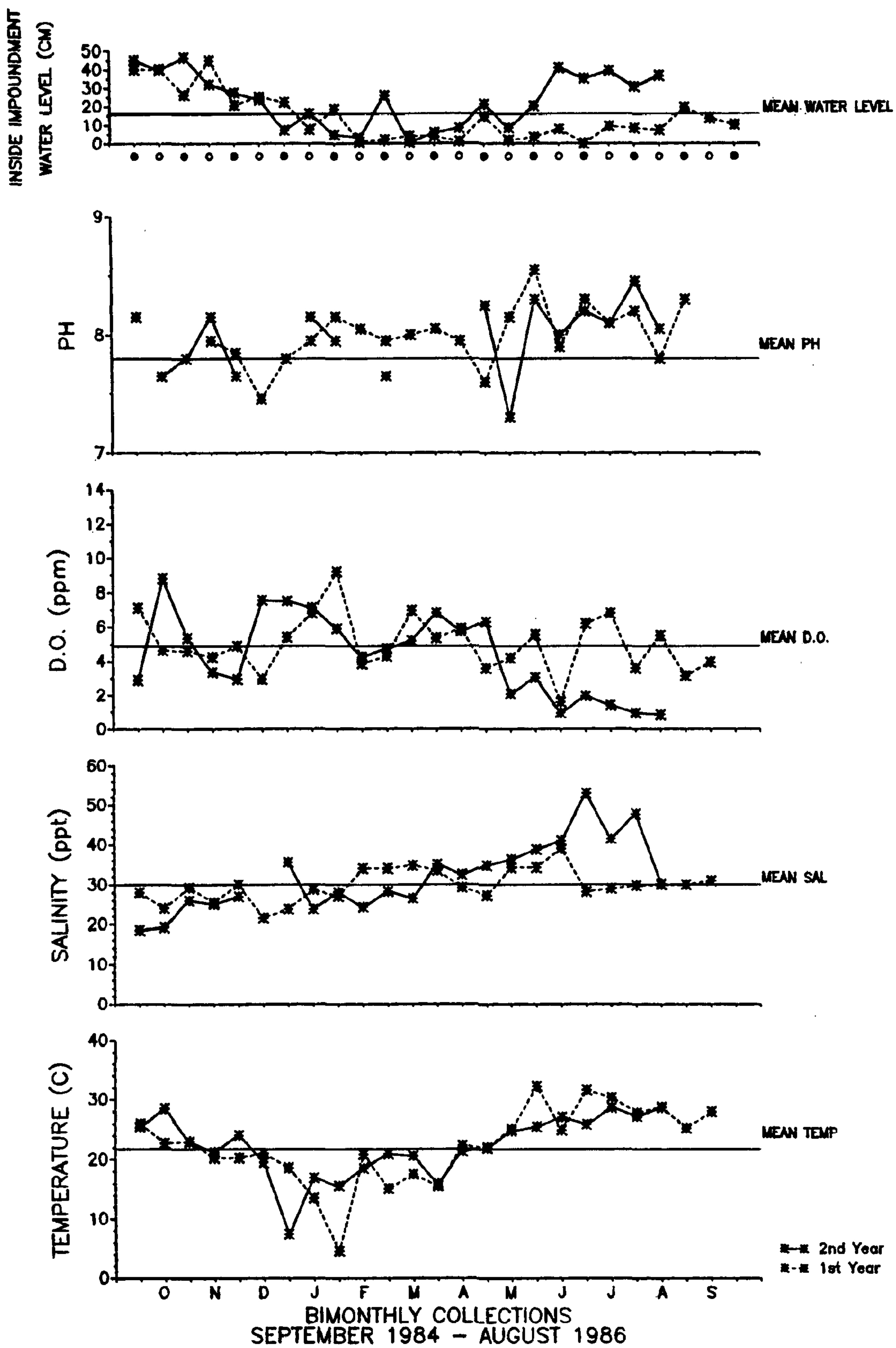
Figure 4. Physical data comparisons of temperature, salinity, dissolved oxygen, pH, and inside impoundment water level for culvert station 61 of Impoundment No. 12 from September 1984 through August 1986.



STATION 61

Figure 4.

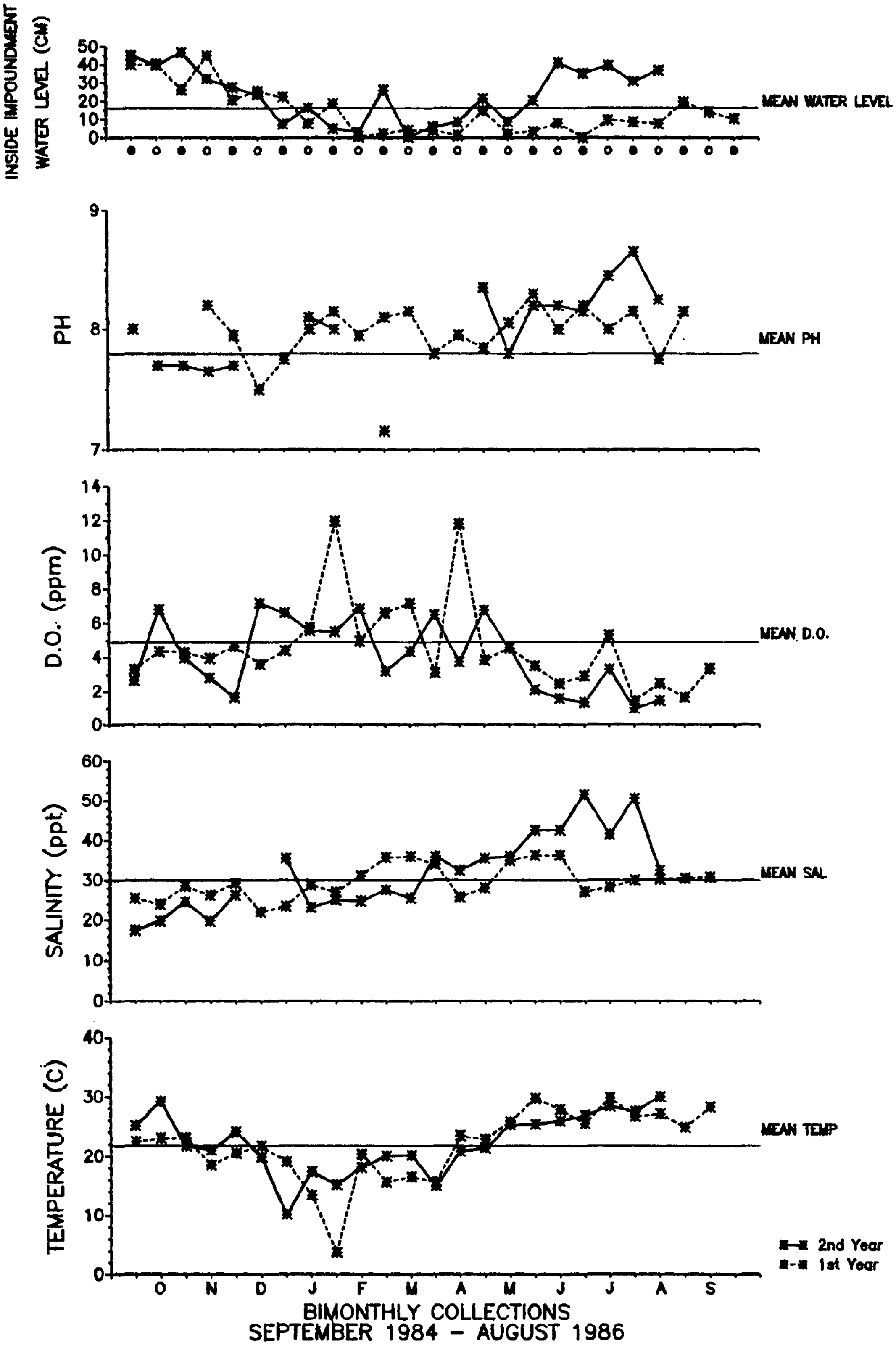
Figure 5. Physical data comparisons of temperature, salinity, dissolved oxygen, pH, and inside impoundment water level for pull net station 71 of Impoundment No. 12 from September 1984 through August 1986.



STATION 71

Figure 5.

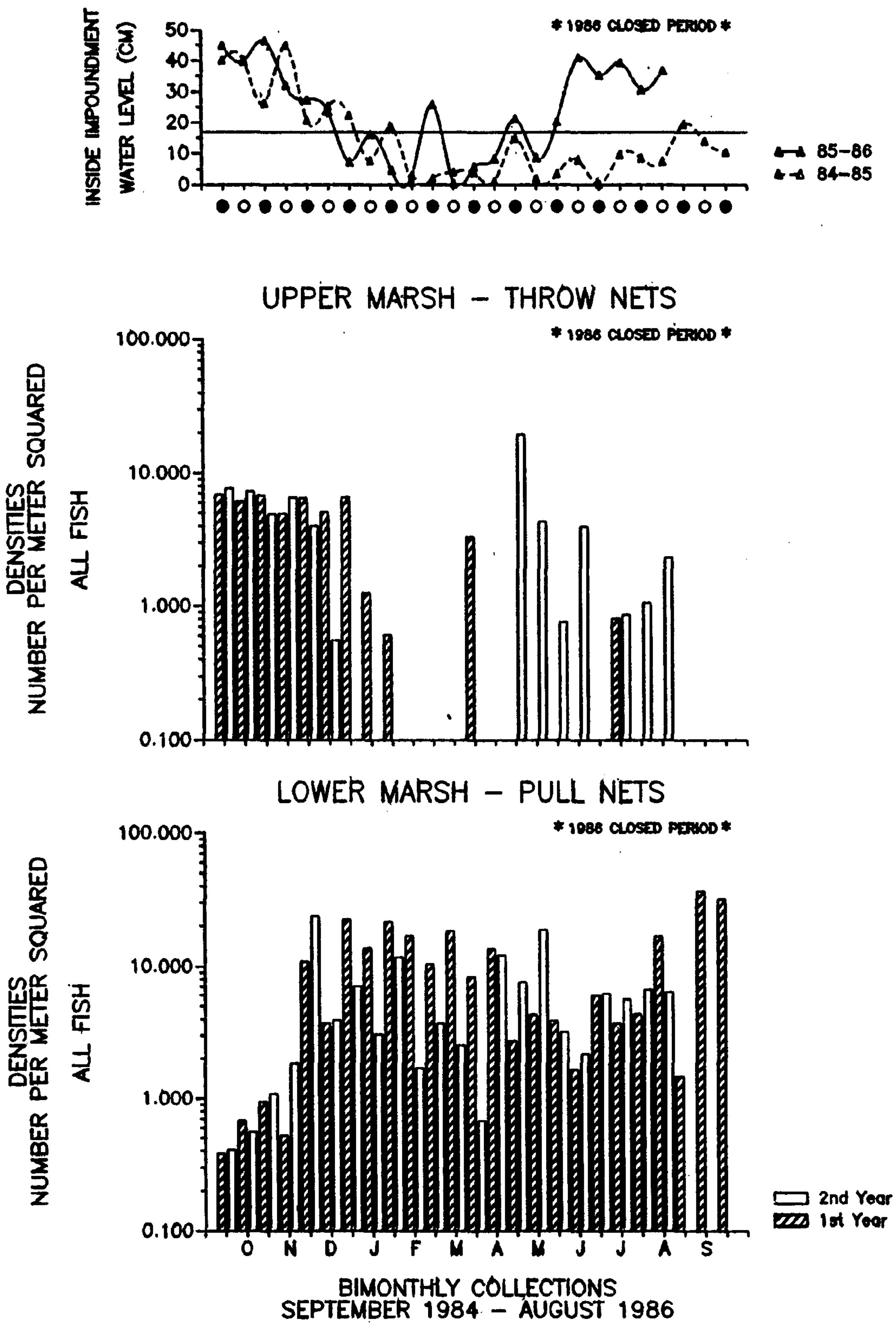
Figure 6. Physical data comparisons of temperature, salinity, dissolved oxygen, pH, and inside impoundment water level for pull net station 60 of Impoundment No. 12 from September 1984 through August 1986.



STATION 60

Figure 6.

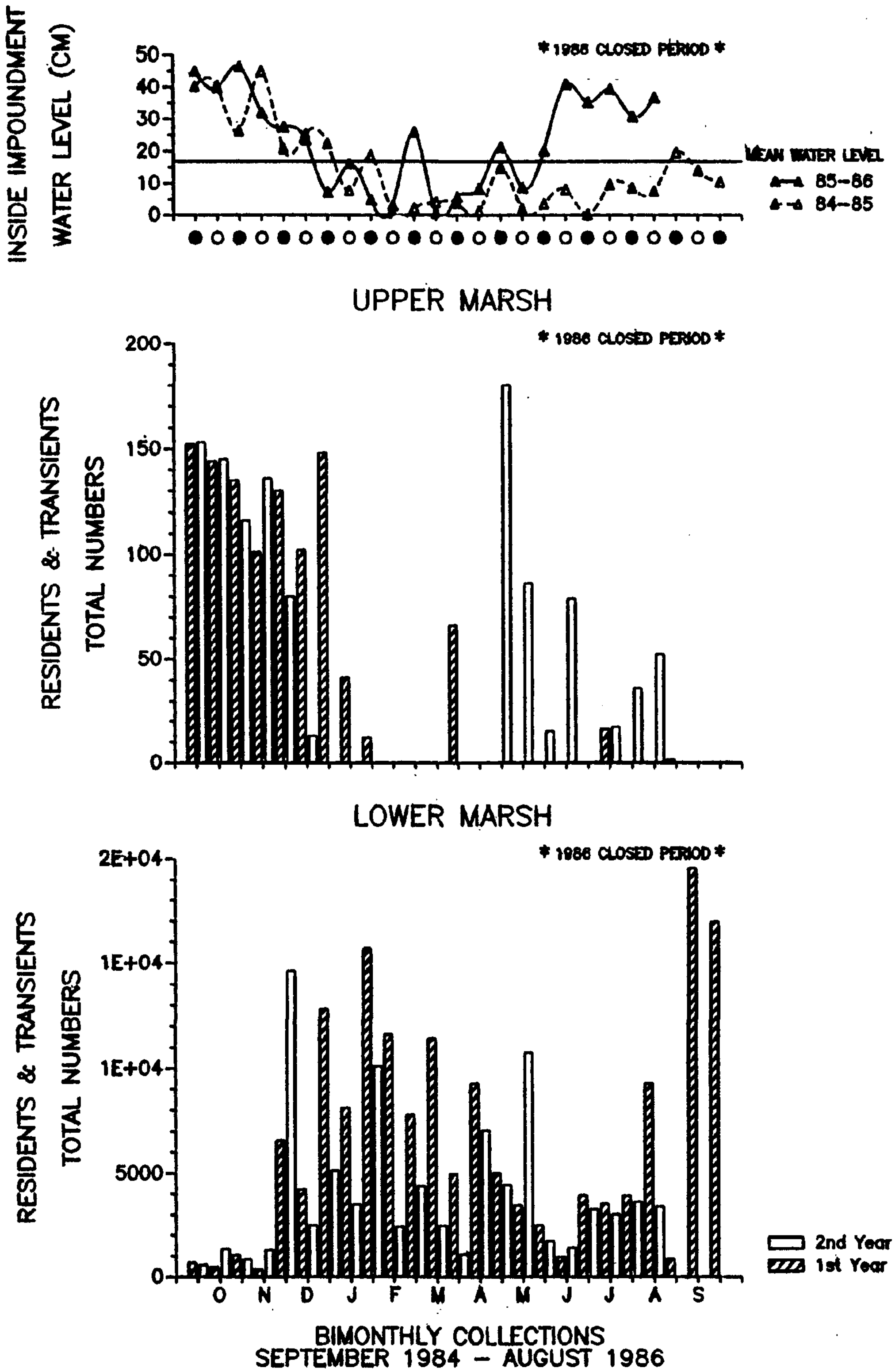
Figure 7. Upper and lower marsh density (number per meter squared) comparisons of fish and macrocrustaceans collected in Impoundment No. 12 from September 1984 through August 1986. Closed management period for 1986 is indicated by asterisks.



INSIDE IMPOUNDMENT WATER LEVEL (CM)
50
40
30
20
10
0
* 1986 CLOSED PERIOD *
85-86
84-85
UPPER MARSH - THROW NETS
DENSITIES NUMBER PER METER SQUARED ALL FISH
100.000
10.000
1.000
0.100
* 1986 CLOSED PERIOD *
LOWER MARSH - PULL NETS
DENSITIES NUMBER PER METER SQUARED ALL FISH
100.000
10.000
1.000
0.100
* 1986 CLOSED PERIOD *
2nd Year
1st Year
O N D J F M A M J J A S
BIMONTHLY COLLECTIONS
SEPTEMBER 1984 - AUGUST 1986

Figure 7.

Figure 8. Comparison of total number of fish and macrocrustaceans collected from the upper and lower marsh of Impoundment No. 12 from September 1984 through August 1986. Closed management period for 1986 is indicated by asterisks.



INSIDE IMPOUNDMENT WATER LEVEL (CM)
* 1986 CLOSED PERIOD *
MEAN WATER LEVEL
85–86
84–85
UPPER MARSH
* 1986 CLOSED PERIOD *
RESIDENTS & TRANSIENTS TOTAL NUMBERS
LOWER MARSH
* 1986 CLOSED PERIOD *
RESIDENTS & TRANSIENTS TOTAL NUMBERS
2nd Year
1st Year
O N D J F M A M J J A S
BIMONTHLY COLLECTIONS
SEPTEMBER 1984 – AUGUST 1986

Figure 8.

Figure 9. Total marsh comparisons of the total number of resident and transient fishes and macrocrustaceans collected in Impoundment No. 12 from September 1984 through August 1986. Closed management period for 1986 is indicated by asterisks.

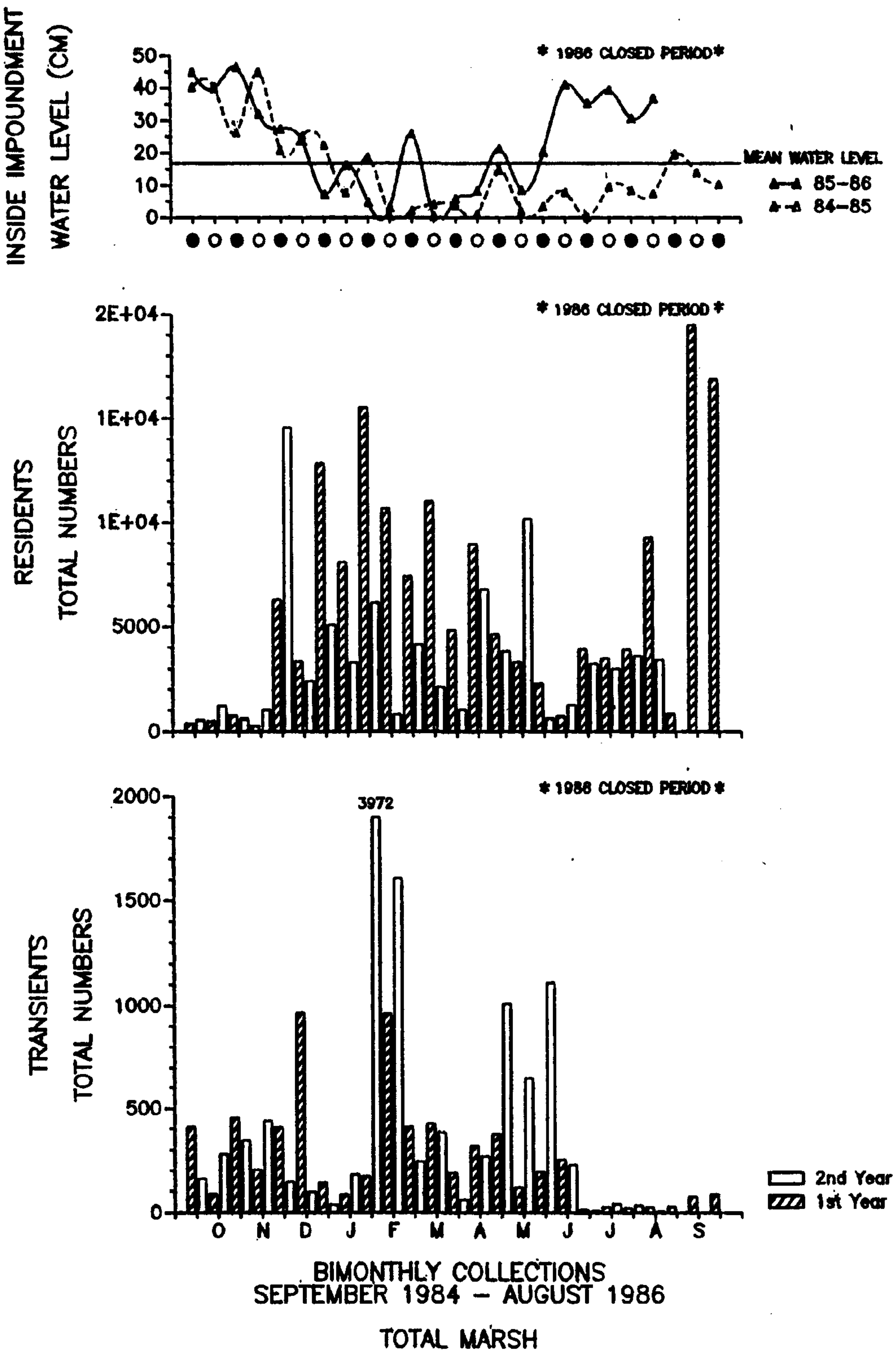

INSIDE IMPOUNDMENT
WATER LEVEL (CM)
50
40
30
20
10
0
* 1986 CLOSED PERIOD*
MEAN WATER LEVEL
85-86
84-85
RESIDENTS
TOTAL NUMBERS
2E+04
1E+04
1E+04
5000
0
* 1986 CLOSED PERIOD *
TRANSIENTS
TOTAL NUMBERS
2000
1500
1000
500
0
3972
* 1986 CLOSED PERIOD *
2nd Year
1st Year
O N D J F M A M J J A S
BIMONTHLY COLLECTIONS
SEPTEMBER 1984 – AUGUST 1986
TOTAL MARSH

Figure 9.

Figure 10. Upper and lower marsh comparisons of the total number of resident and transient fishes and macrocrustaceans collected in Impoundment No. 12 from September 1984 through August 1986. Closed management period for 1986 is indicated by asterisks.

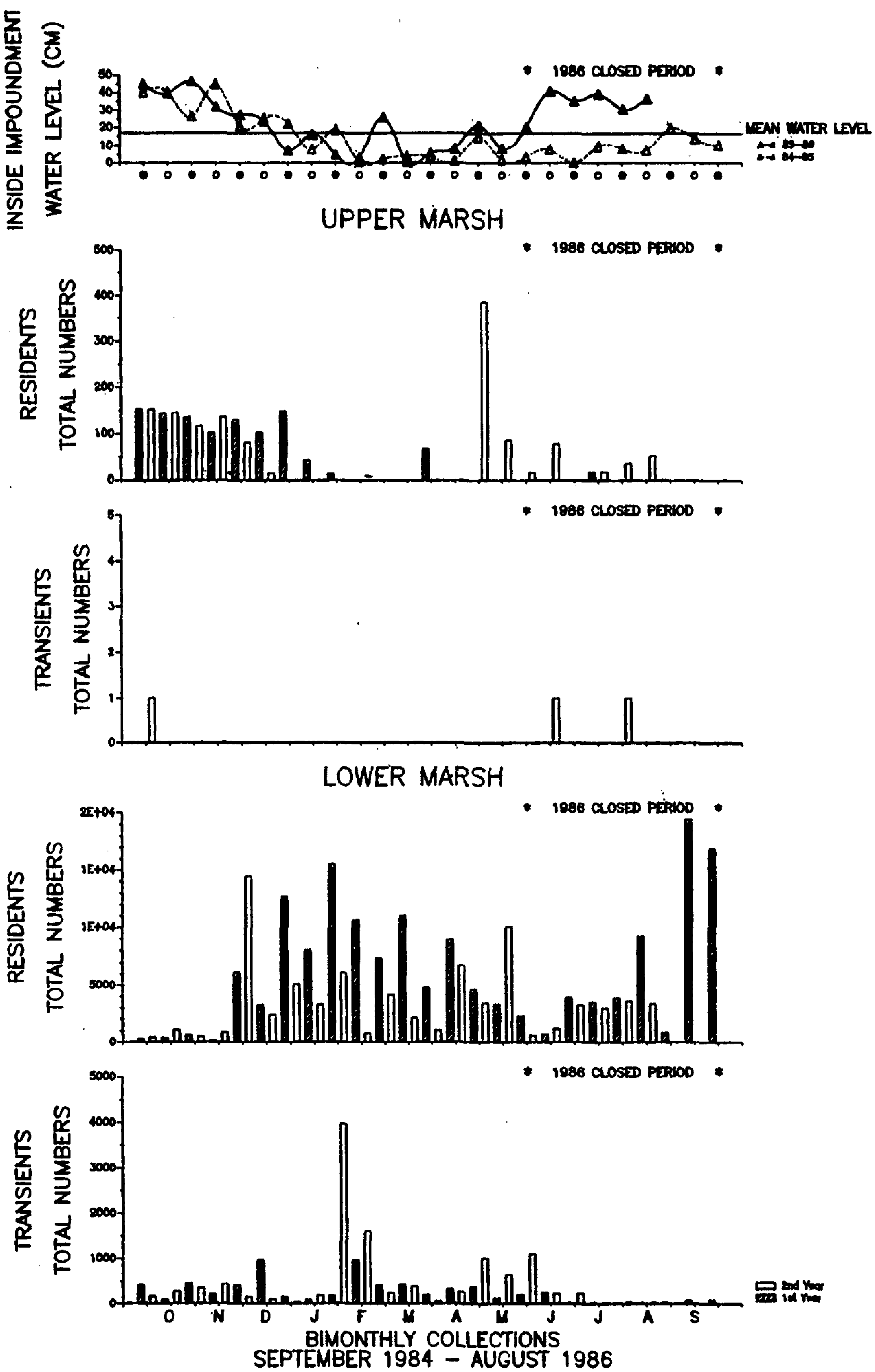

INSIDE IMPOUNDMENT WATER LEVEL (CM)
* 1986 CLOSED PERIOD *
MEAN WATER LEVEL
UPPER MARSH
RESIDENTS TOTAL NUMBERS
TRANSIENTS TOTAL NUMBERS
LOWER MARSH
RESIDENTS TOTAL NUMBERS
TRANSIENTS TOTAL NUMBERS
2nd Year
1st Year
O N D J F M A M J J A S
BIMONTHLY COLLECTIONS
SEPTEMBER 1984 – AUGUST 1986

Figure 10.

Figure 11. Upper and lower marsh density (number per meter squared) comparisons for *Mugil cephalus* collected in Impoundment No. 12 from September 1984 through August 1986. Closed management period for 1986 is indicated by asterisks.

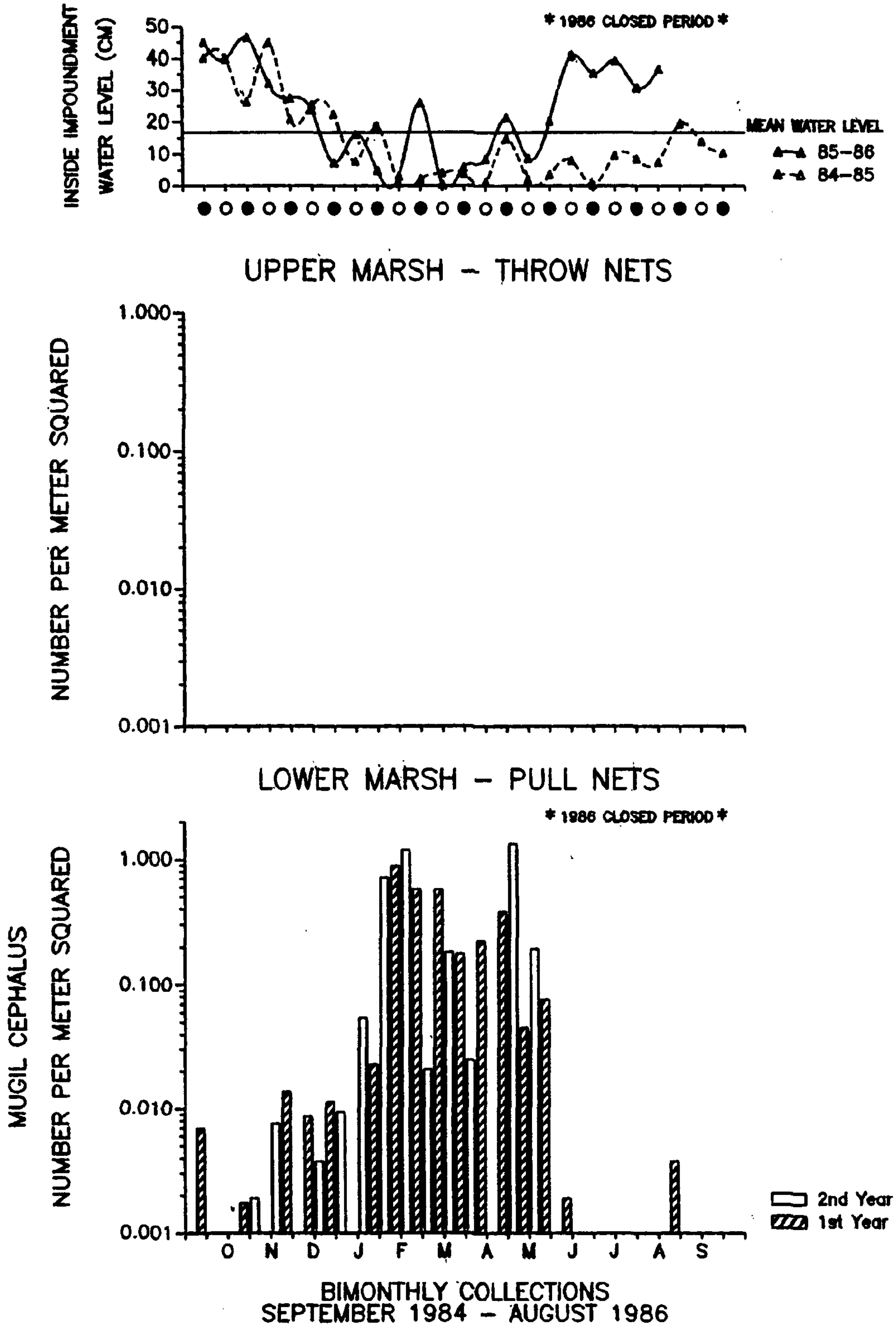
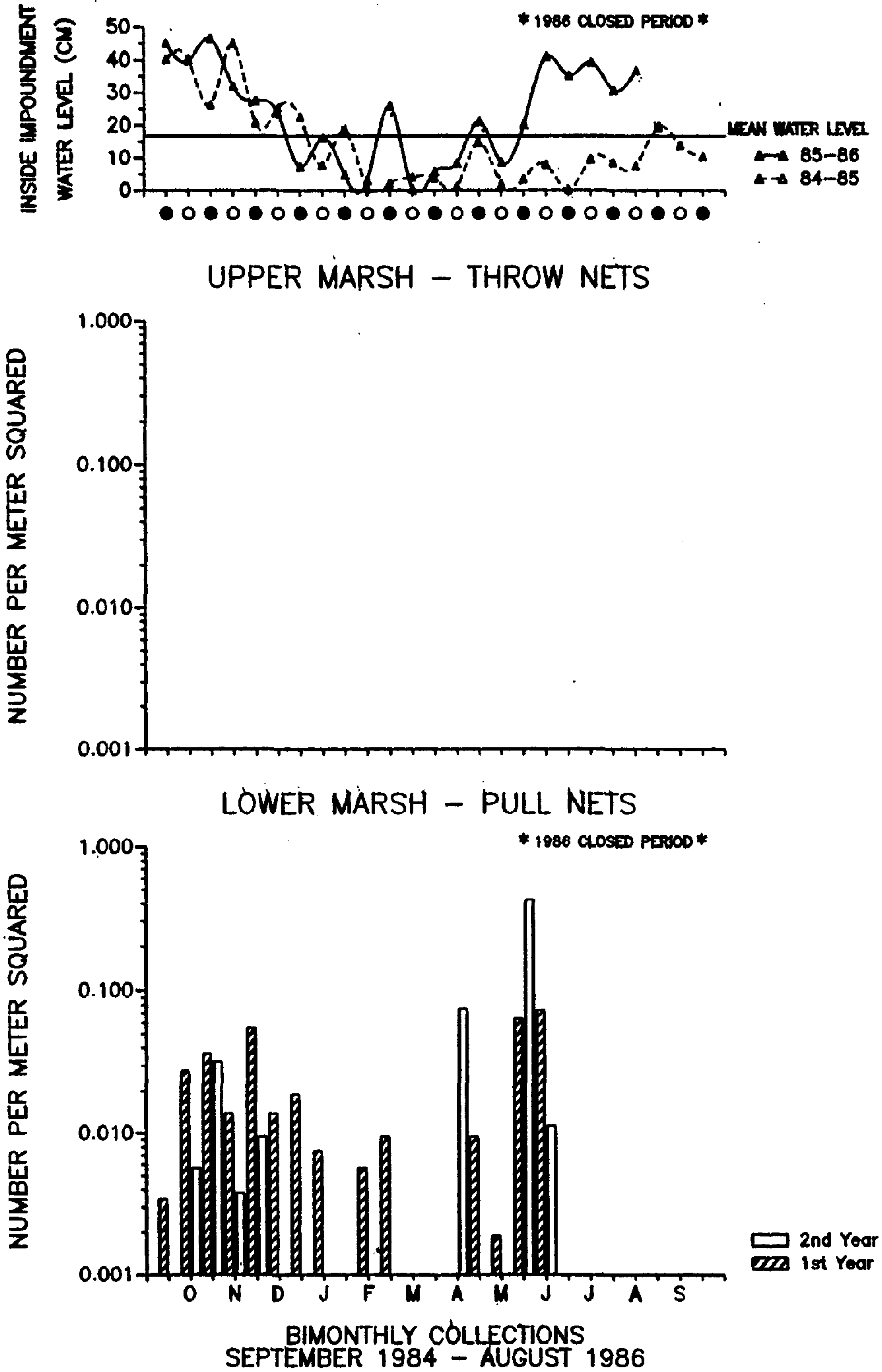

INSIDE IMPOUNDMENT WATER LEVEL (CM)
* 1986 CLOSED PERIOD *
MEAN WATER LEVEL
85-86
84-85
UPPER MARSH - THROW NETS
NUMBER PER METER SQUARED
LOWER MARSH - PULL NETS
* 1986 CLOSED PERIOD *
MUGIL CEPHALUS
NUMBER PER METER SQUARED
2nd Year
1st Year
O N D J F M A M J J A S
BIMONTHLY COLLECTIONS
SEPTEMBER 1984 - AUGUST 1986

Figure 11.

Figure 12. Upper and lower marsh density (number per meter squared) comparisons for *Mugil curema* collected in Impoundment No. 12 from September 1984 through August 1986. Closed management period for 1986 is indicated by asterisks.



INSIDE IMPOUNDMENT WATER LEVEL (CM)
* 1986 CLOSED PERIOD *
MEAN WATER LEVEL
85-86
84-85
UPPER MARSH - THROW NETS
MUGIL CUREMA
NUMBER PER METER SQUARED
LOWER MARSH - PULL NETS
* 1986 CLOSED PERIOD *
MUGIL CUREMA
NUMBER PER METER SQUARED
2nd Year
1st Year
O N D J F M A M J J A S
BIMONTHLY COLLECTIONS
SEPTEMBER 1984 - AUGUST 1986

Figure 12.

Figure 13. Upper and lower marsh density (number per meter squared) comparisons for Elops saurus collected in Impoundment No. 12 from September 1984 through August 1986. Closed management period for 1986 is indicated by asterisks.

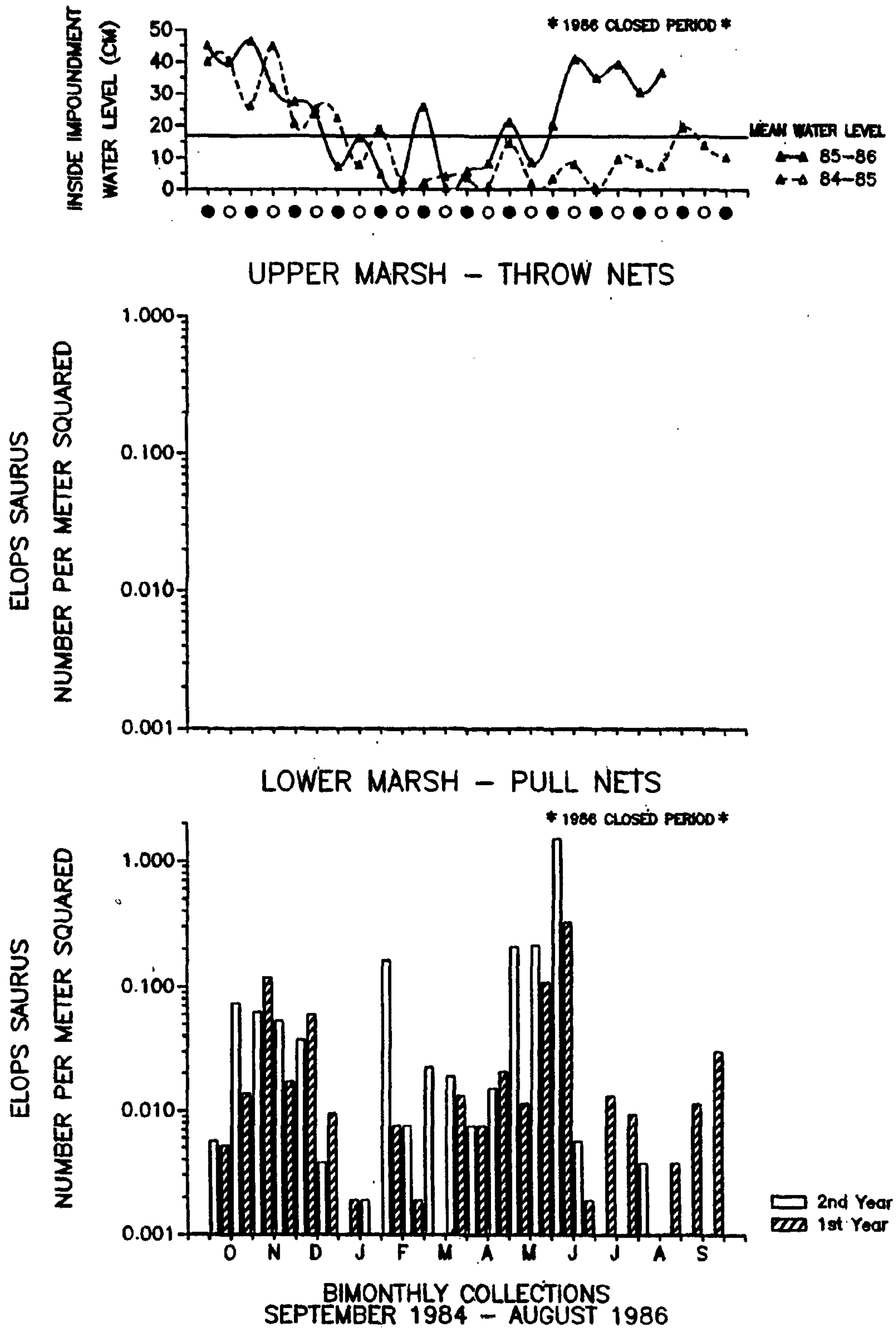
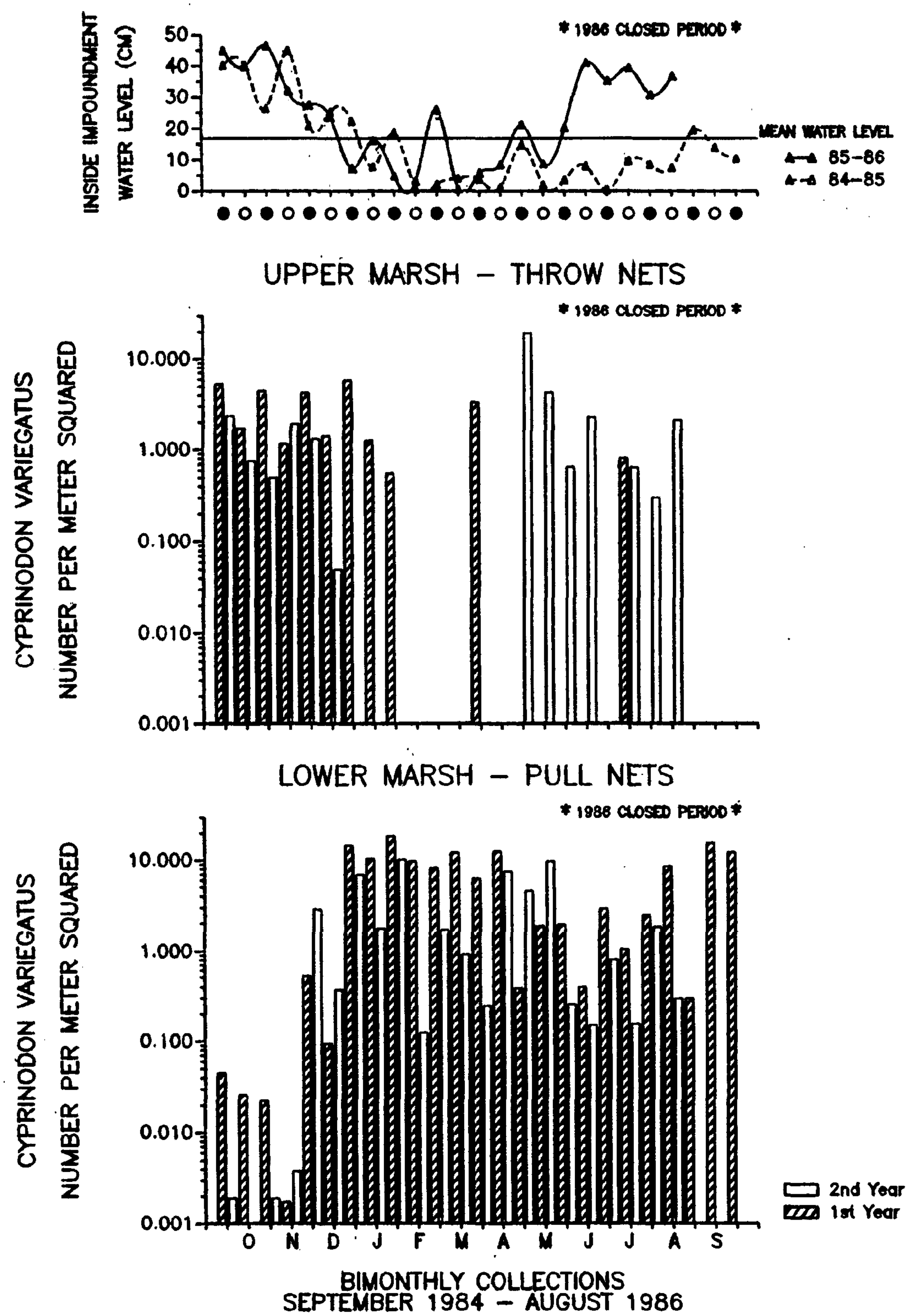

INSIDE IMPOUNDMENT WATER LEVEL (CM)
* 1986 CLOSED PERIOD *
MEAN WATER LEVEL
85-86
84-85
UPPER MARSH - THROW NETS
ELOPS SAURUS
NUMBER PER METER SQUARED
LOWER MARSH - PULL NETS
* 1986 CLOSED PERIOD *
2nd Year
1st Year
O N D J F M A M J J A S
BIMONTHLY COLLECTIONS
SEPTEMBER 1984 - AUGUST 1986

Figure 13.

Figure 14. Upper and lower marsh density (number per meter squared) comparisons for *Cyprinodon variegatus* collected in Impoundment No. 12 from September 1984 through August 1986. Closed management period for 1986 is indicated by asterisks.



INSIDE IMPOUNDMENT WATER LEVEL (CM)
50
40
30
20
10
0
* 1986 CLOSED PERIOD *
MEAN WATER LEVEL
85-86
84-85
UPPER MARSH - THROW NETS
* 1986 CLOSED PERIOD *
CYPRINODON VARIEGATUS NUMBER PER METER SQUARED
10.000
1.000
0.100
0.010
0.001
LOWER MARSH - PULL NETS
* 1986 CLOSED PERIOD *
CYPRINODON VARIEGATUS NUMBER PER METER SQUARED
10.000
1.000
0.100
0.010
0.001
O N D J F M A M J J A S
2nd Year
1st Year
BIMONTHLY COLLECTIONS
SEPTEMBER 1984 - AUGUST 1986

Figure 13.

Figure 15. Upper and lower marsh density (number per meter squared) comparisons for *Poecilia latipinna* collected in Impoundment No. 12 from September 1984 through August 1986. Closed management period for 1986 is indicated by asterisks.

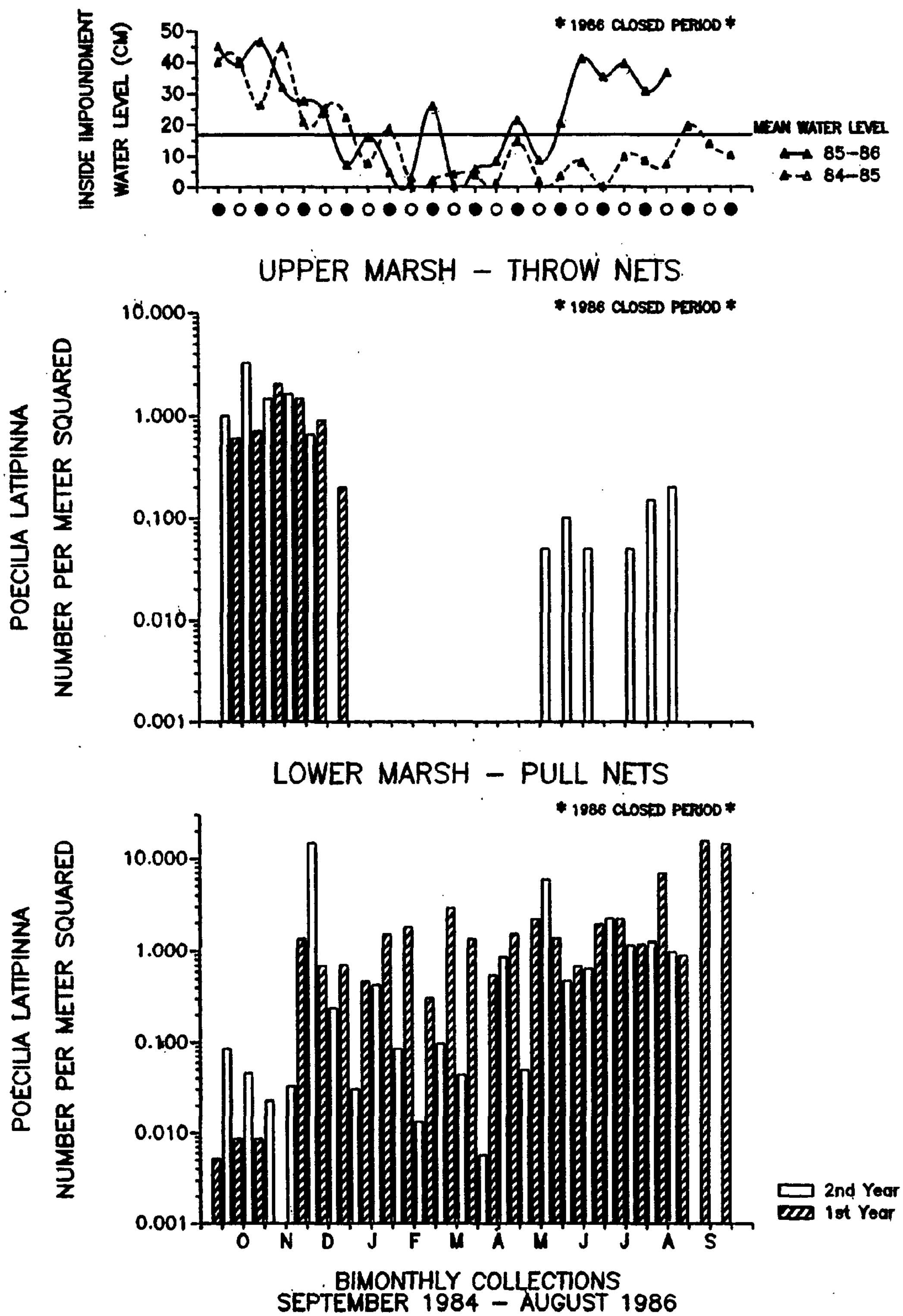
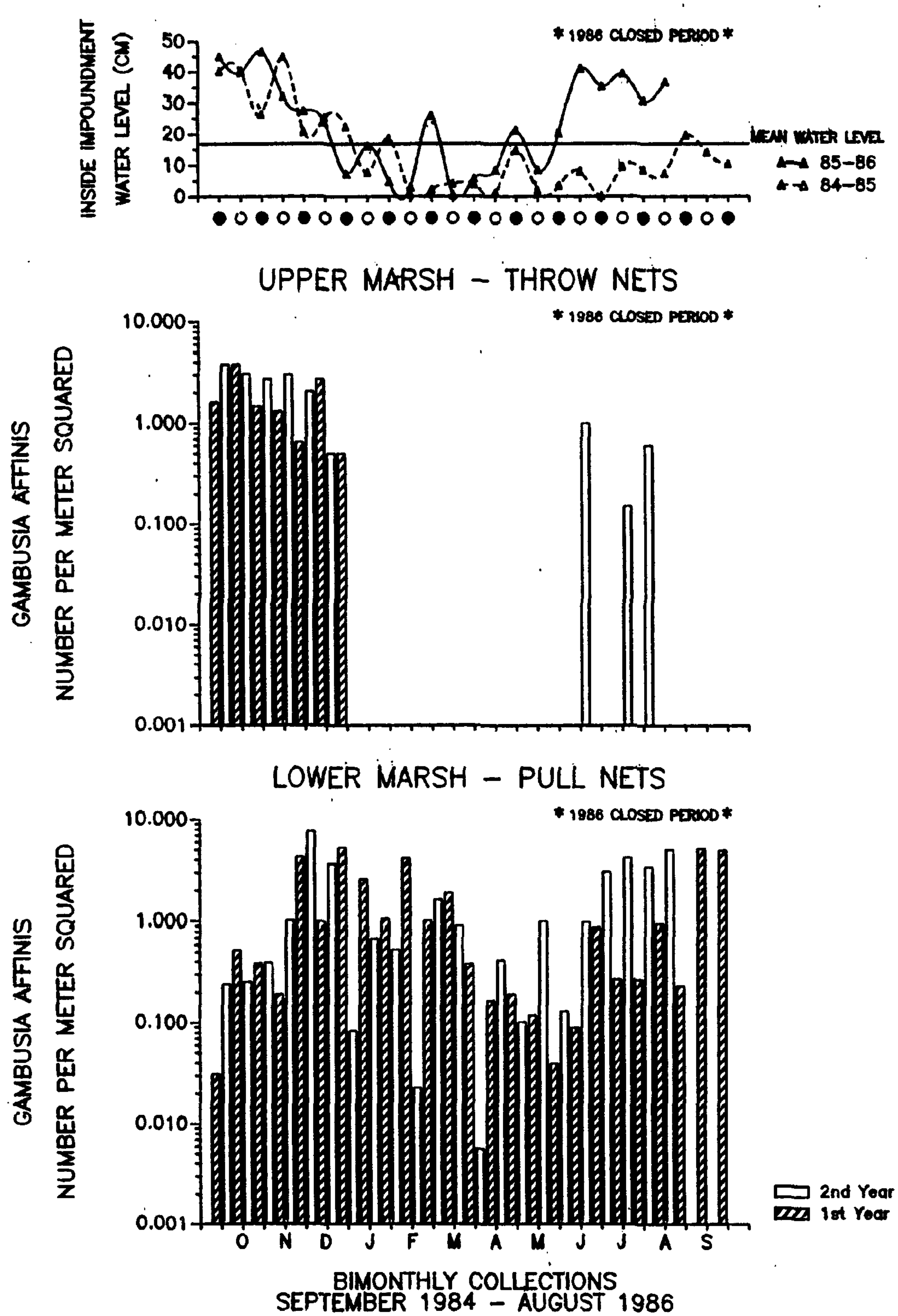

INSIDE IMPOUNDMENT WATER LEVEL (CM)
* 1986 CLOSED PERIOD *
MEAN WATER LEVEL
85-86
84-85
UPPER MARSH - THROW NETS
POECILIA LATIPINNA
NUMBER PER METER SQUARED
LOWER MARSH - PULL NETS
2nd Year
1st Year
O N D J F M A M J J A S
BIMONTHLY COLLECTIONS
SEPTEMBER 1984 - AUGUST 1986

Figure 15.

Figure 16. Upper and lower marsh density (number per meter squared) comparisons for *Gambusia affinis* collected in Impoundment No. 12 from September 1984 through August 1986. Closed management period for 1986 is indicated by asterisks.



INSIDE IMPOUNDMENT WATER LEVEL (CM)
50
40
30
20
10
0
* 1986 CLOSED PERIOD *
MEAN WATER LEVEL
85-86
84-85
UPPER MARSH - THROW NETS
* 1986 CLOSED PERIOD *
GAMBUSIA AFFINIS NUMBER PER METER SQUARED
10.000
1.000
0.100
0.010
0.001
LOWER MARSH - PULL NETS
* 1986 CLOSED PERIOD *
GAMBUSIA AFFINIS NUMBER PER METER SQUARED
10.000
1.000
0.100
0.010
0.001
O N D J F M A M J J A S
2nd Year
1st Year
BIMONTHLY COLLECTIONS
SEPTEMBER 1984 - AUGUST 1986

Fugure 16.

Figure 17. Yearly and total study comparisons of the total number of birds observed in Impoundment No. 12 from September 1984 through August 1986. Closed management period for 1986 is indicated by asterisks.

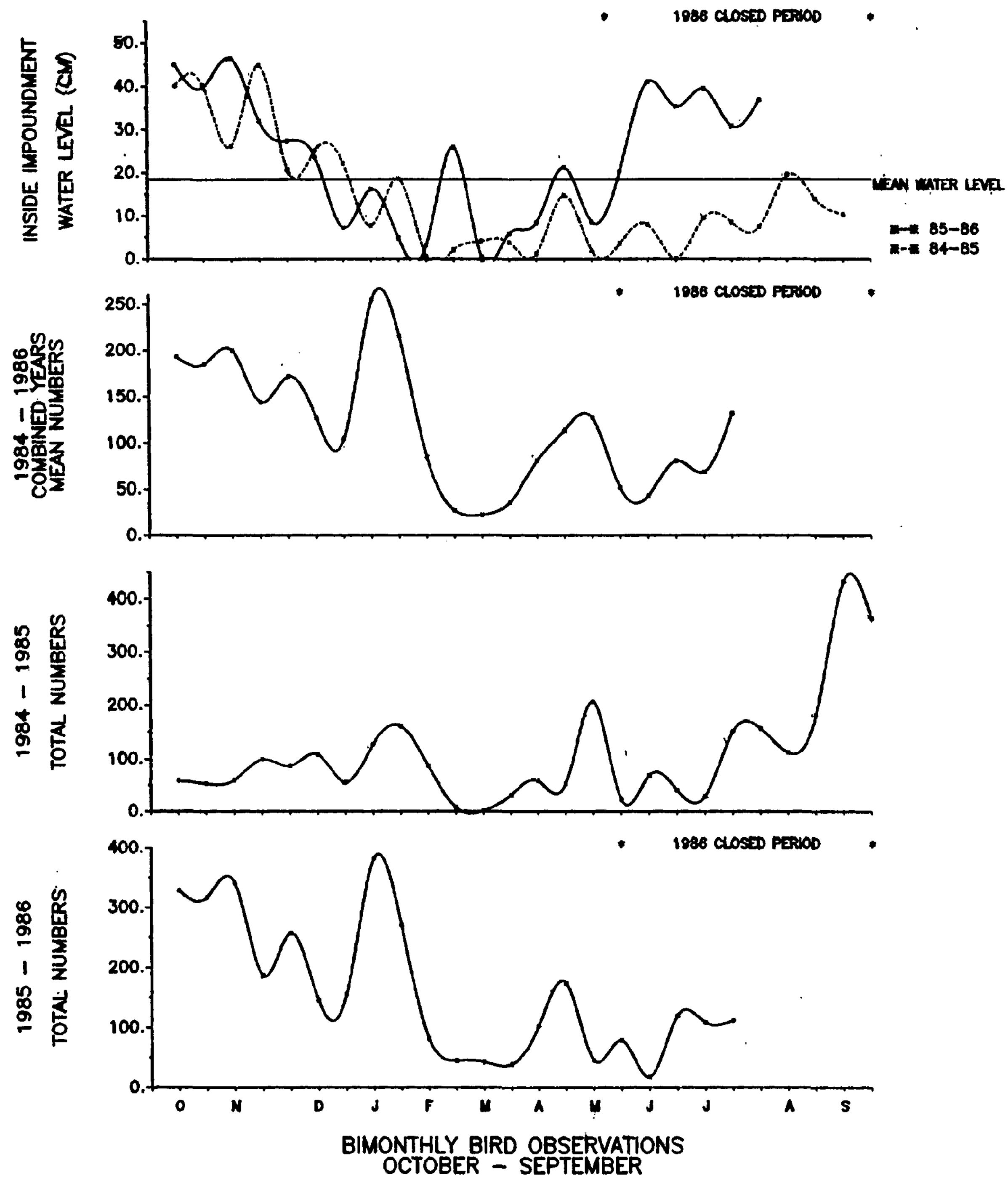
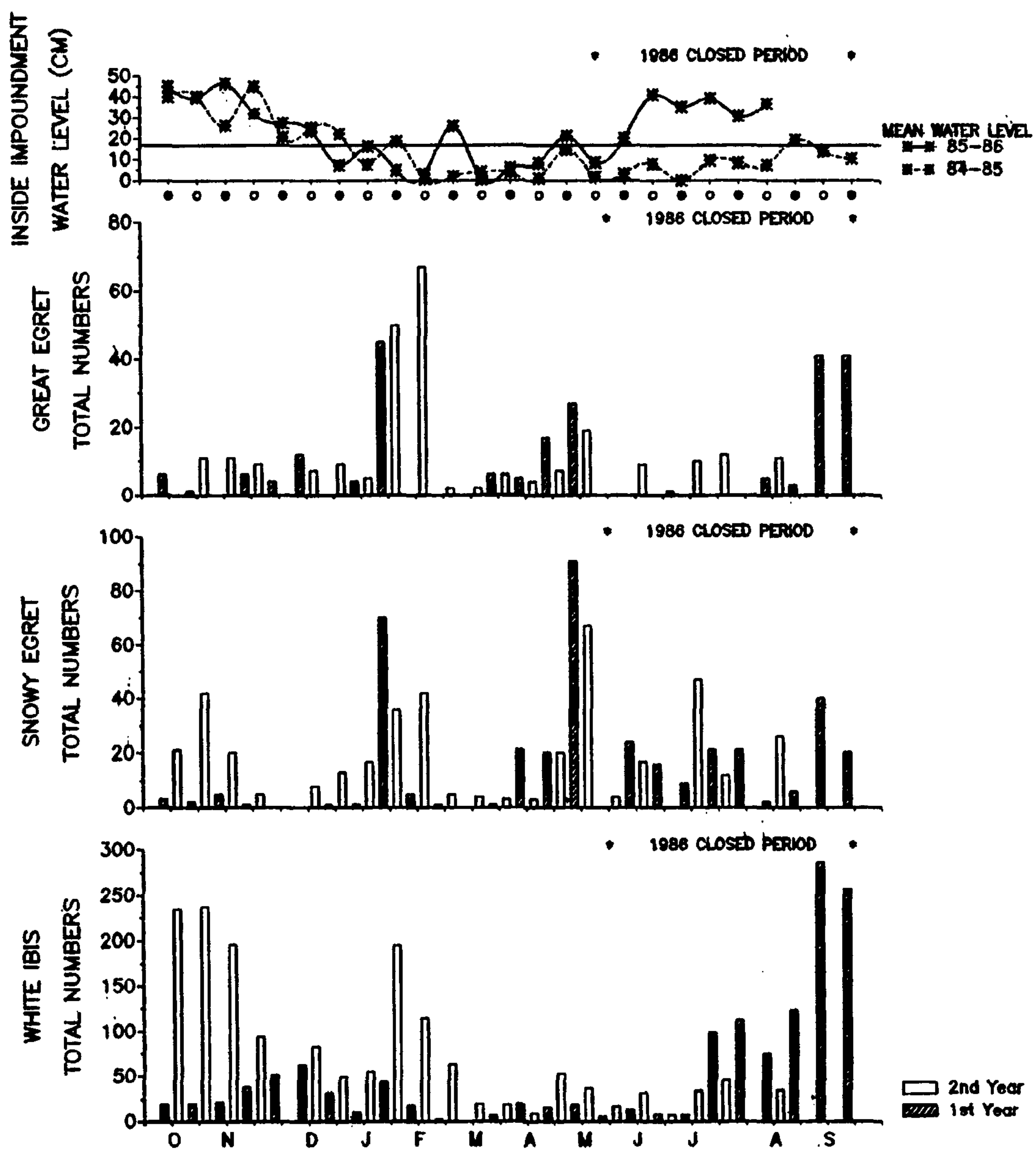

1986 CLOSED PERIOD
INSIDE IMPOUNDMENT WATER LEVEL (CM)
50.
40.
30.
20.
10.
0.
MEAN WATER LEVEL
85-86
84-85
1984 - 1986 COMBINED YEARS MEAN NUMBERS
250.
200.
150.
100.
50.
0.
1984 - 1985 TOTAL NUMBERS
400.
300.
200.
100.
0.
1985 - 1986 TOTAL NUMBERS
O
N
D
J
F
M
A
M
J
J
A
S
BIMONTHLY BIRD OBSERVATIONS
OCTOBER - SEPTEMBER

Figure 17.

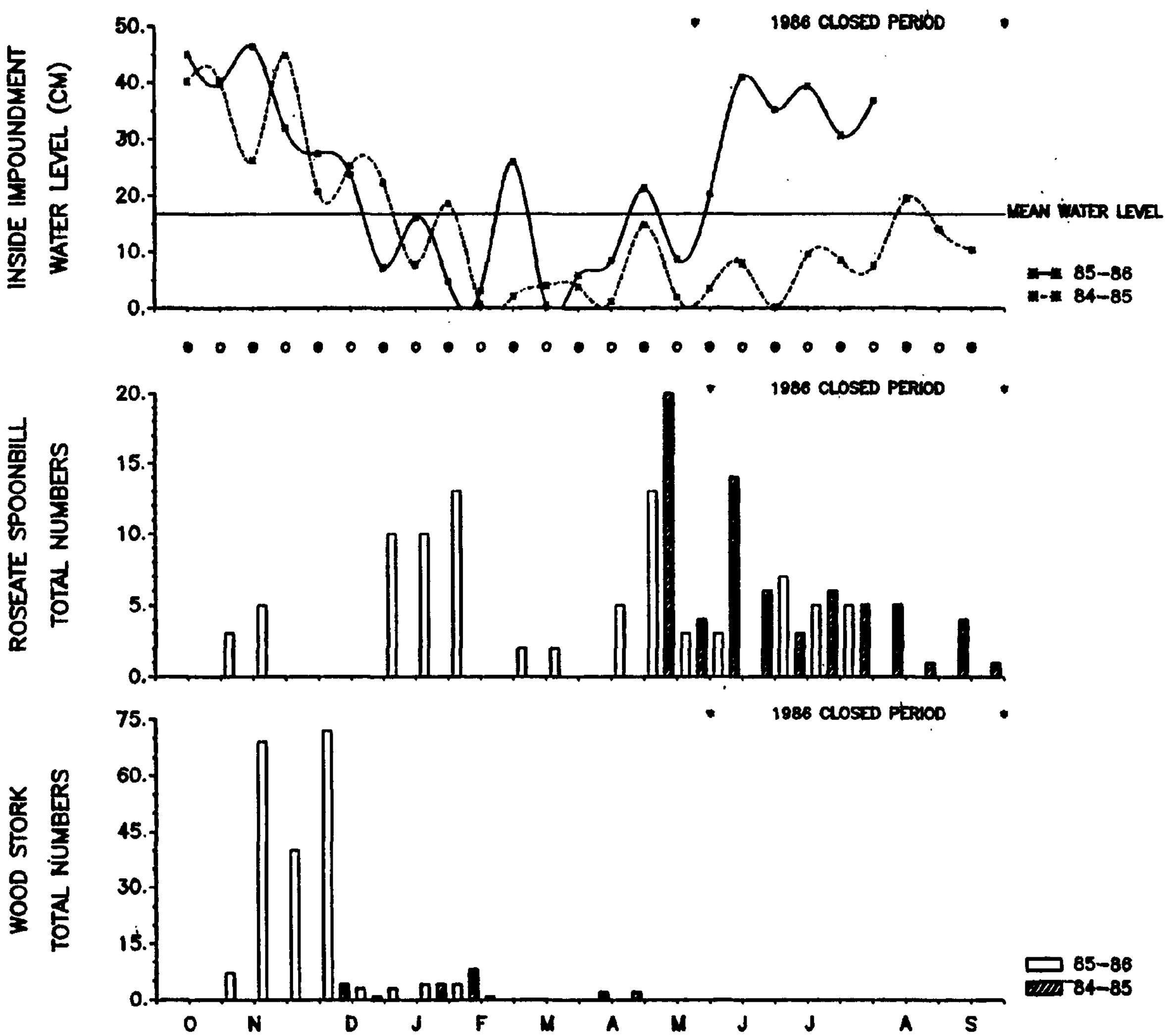
Figure 18. Comparison of the total number of White Ibis, Snowy Egrets, and great Egrets observed in Impoundment No. 12 from September 1984 through August 1986. Closed management period for 1986 is indicated by asterisks.



BIMONTHLY BIRD OBSERVATIONS
OCTOBER 1984 – AUGUST 1986

Figure 18.

Figure 19. Comparison of the total number of Wood Storks and Roseate Spoonbills observed in Impoundment No. 12 from September 1984 through August 1986. Closed management period for 1986 is indicated by asterisks.



BIMONTHLY BIRD OBSERVATIONS
OCTOBER 1984 – AUGUST 1986

Figure 19.

Figure 20. Comparison of the total number of birds observed during the opened and closed management periods from the south, central, and north quads of Impoundment No. 12 from September 1984 through August 1986. Closed management period for 1986 is indicated by asterisks.

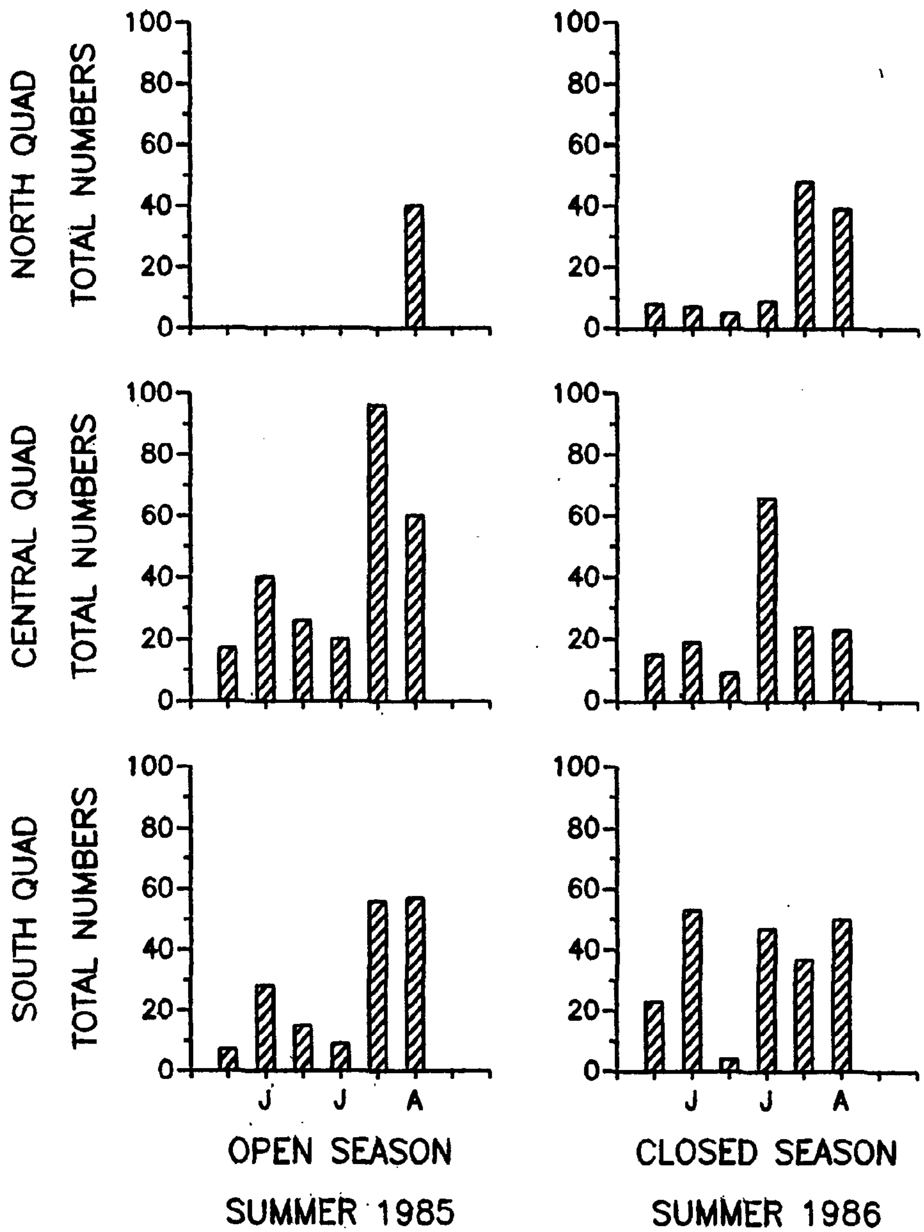
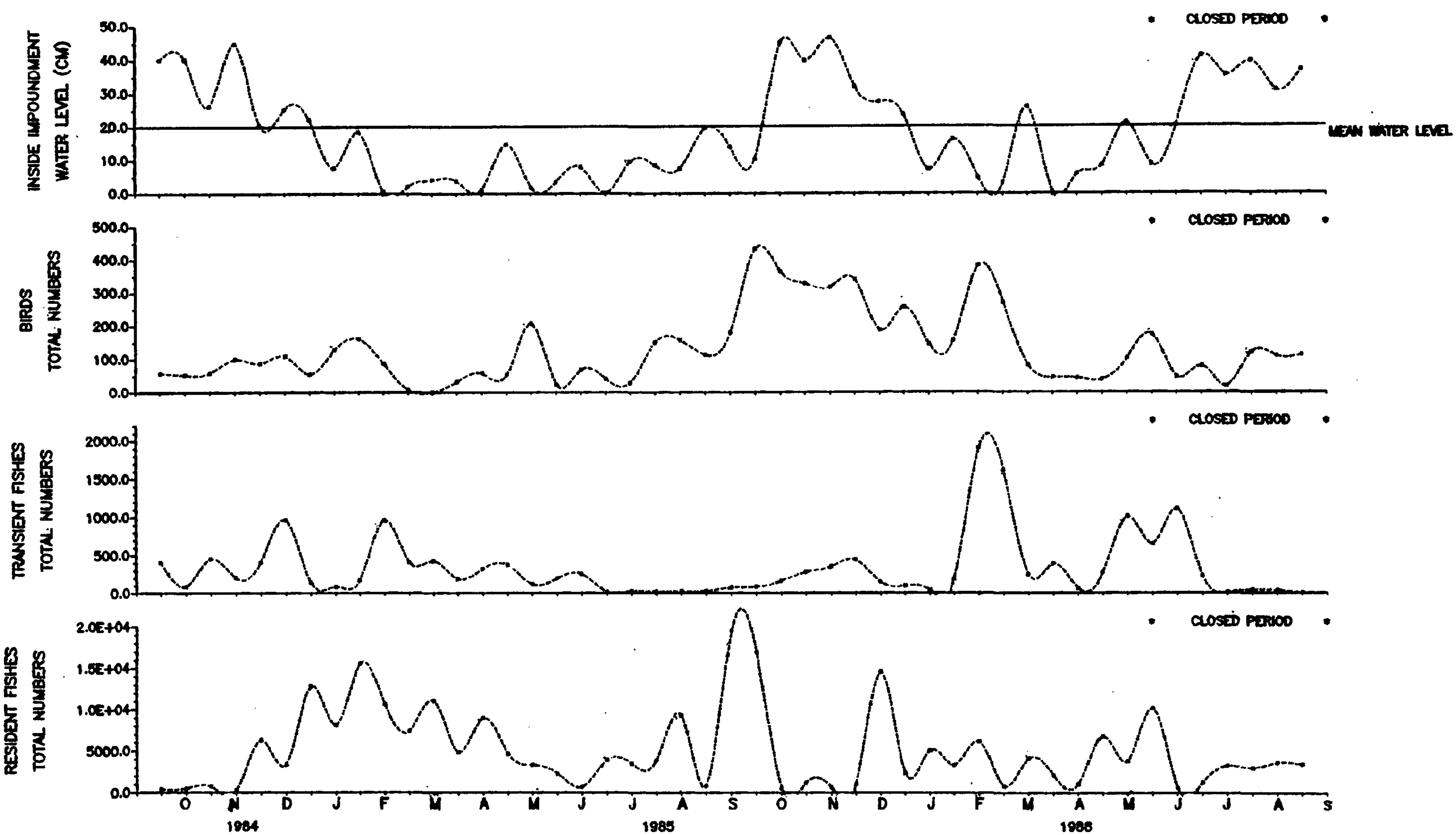

NORTH QUAD
CENTRAL QUAD
SOUTH QUAD
TOTAL NUMBERS
100
80
60
40
20
0
J
J
A
OPEN SEASON
SUMMER 1985
CLOSED SEASON
SUMMER 1986

Figure 20.

Figure 21. Comparison of the total number of resident and transient fishes and macrocrustaceans and birds observed in Impoundment No. 12 from September 1984 through August 1986. Closed management period for 1986 is indicated by asterisks.



BIMONTHLY COLLECTIONS & OBSERVATIONS
SEPTEMBER 1984 – AUGUST 1986

FISHES & BIRDS

Figure 21.

B

VEGETATION, ZOOPLANKTON & WATER QUALITY

JORGE R. REY

ROY CROSSMAN, TIM KAIN, SCOTT TAYLOR, PETE O'BRIAN

University of Florida - IFAS
Florida Medical Entomology Laboratory
200 9th Street S.E.
Vero Beach, FL 32962

September 1986

PART ONE - GENERAL INTRODUCTION

INTRODUCTION

From 1955 to 1963, 33,518 acres of salt marshes bordering the Indian River, the Banana River, and Mosquito Lagoon in east-central Florida were impounded for mosquito control. These marshes were oviposition sites for the salt marsh mosquitoes *Aedes taeniorhynchus* and *A. sollicitans*. In Florida, salt marsh mosquito impoundments are usually managed by local mosquito control agencies, and management practices, as well as chemical treatment methods for mosquito control vary from district to district.

Although there is a great deal of information available on salt marshes and mangrove swamps, there are huge gaps in our knowledge of the biology of these areas (Clewell 1979), and very scant data on the biology and ecology of salt marsh impoundments.

STUDY AREA

The study area is located in the Indian River lagoon in east-central Florida (30.48° N, 80.75° W). It consists of two impounded salt marshes, Impoundments IRC #12 and SLC #24, on the barrier island side of the Indian River, as well as the adjoining lagoon waters.

Impoundment IRC #12 covers an area of 50.4 ha. Prior to impoundment, the vegetation in the area was typical of high marshes in the region, consisting of *Batis maritima*, *Salicornia virginica*, and *Salicornia bigelovii* meadows, with black mangroves (*Avicennia germinans*) and white mangroves (*Laguncularia racemosa*) interspersed throughout the marsh (Harrington & Harrington 1961, 1982). After water management for mosquito control was discontinued at the request of the property owner, most of this vegetation disappeared due to the hypersaline conditions that quickly developed (Gilmore et al. 1981). Subsequent opening of the culvert resulted in regrowth of the marsh floor halophytes (Batis and Salicornia), however, only minimal mangrove recovery has been observed (Rey et al. 1986). A more complete description of impoundment IRC # 12 is given in the first part of this report by Carlson and Vigliano.

Impoundment SLC #24 lies immediately to the south of IRC #12. Although larger than IRC #12 (122 ha) it is similar in structure except that during most of the study it has been isolated from the lagoon.

REPORT ORGANIZATION, DATA, AND PROJECT STATUS

Organization.

This report is divided into four sections: 1) This General Introduction, 2) Marsh Vegetation, 3) Zooplankton Dynamics, 4) Water Quality. The sections are relatively independent and as result there is a small amount of repetition in the sections describing sampling sites. All the sections share a common reference listing and common Tables and Figures sections with consecutive numbering.

Data.

The data presented here is as current as possible. Every effort was made to include all of the data available at the time of writing. It should be emphasized, however, that many of the studies included here are still ongoing or just finished, a fact that precludes the inclusion in this report of results of complex statistical analysis of the data. Given the massive amount of information generated by this project, such analyses will be necessary to identify patterns and processes at work in the systems under study.

Status.

VEGETATION. Vegetation sampling has been accomplished on schedule, and most of the data to date has been tabulated and entered into the computer. Sampling for percent cover along the transects and measurement of mangrove growth rates will be continued during the coming year. Monitoring of the effects of pumping upon the marsh vegetation will be continued for an undetermined period of time.

ZOOPLANKTON. Although the field portion of the zooplankton dynamics study has been completed, we continue to work on the counting, identifying and tabulation portion of the study. Significant progress on these aspects of the project has been made during the past year. We anticipate that all the data will be processed and ready for analysis by December of 1986. The data processed to date is included in this report, and some easily-identified patterns are discussed.

WATER QUALITY. At this time, the last samples (September 10-11, 1986) from the water quality portion of this study are being analyzed in our laboratory. During the past year we have eliminated the backlog of samples present and have processed most of the data. We are still a couple of samples behind in the conversion of autoanalyzer output into actual concentrations and in entry of these data into the master data tables, but the whole process will be finished shortly. Analysis of these data will be extremely time-consuming because of the large amount of data that has been produced, because of its complexity, and because of the many, and often subtle, interactions possible between the variables. An overview of the first year's data set is included in the Water Quality section merely as an example of the type of data that has been generated. Analysis of these results will commence as soon as the complete data set is processed.

VEGETATION PRODUCTION. Preparations for next year's study of vegetation production are already under way. Sites have been selected and marked and the litter bags have been constructed, packed with dry vegetation, and set out in their designated locations. We are presently building the quadrat samplers and preparing the thermographs for field operation.

PART TWO - MARSH VEGETATION

INTRODUCTION

The prime mosquito-producing portion of a salt marsh is that area of the marsh above the influence of daily tidal innundation, the high marsh, (Provost 1974). Frequent tidal flooding of the low marsh does not provide the opportunity for salt marsh mosquitoes to oviposit since they will not lay their eggs upon standing water or overly-moist soil. In south Florida, the low marsh is usually dominated by the red mangrove, Rhizophora mangle and a number of halophytic grasses such as smooth cordgrass (Spartina alterniflora), whereas in the high marsh black mangroves (Avicennia germinans), white mangroves (Laguncularia racemosa) saltwort (Batis maritima) and glasswort (Salicornia spp.) predominate. Further north, Spartina alterniflora predominates in the low marsh and S. patens, Distichlis spicata and Juncus roemerianus in the high marsh.

It is not at all clear what physical-chemical factors affect the zonation of species in salt marshes. Clearly, the frequency and extent of tidal innundation has to be important, but there is a plethora of direct and indirect effects associated with different tidal regimes that need to be separated so that their interaction with plant physiology and ecology can be identified. Bordeau and Adams (1956) list micro-relief, soil texture, and soil salinity as the major factors influencing zonation in North Carolina. Other factors that have been considered important in this respect are: submergence-emergence ratios (Johnson and York 1915), tide-elevation influences (Adams 1963), water quality (Odum et al. (1982), nutrient levels (McCoy 1969), propagule availability (Rabinowitz 1978), and catastrophic events (Ball 1980). These factors obviously overlap and the list barely scratches the surface of the possible interactions among physical-chemical factors, plant physiology, and plant ecology. The list has been presented mainly to illustrate the complexities and subtleties involved in study of salt marsh plant communities.

It has now become evident that salt marsh plant species zones do not simply represent seral stages of succession, but that geomorphological and hydrological processes (Thom 1967, Chapman 1970), local conditions (Odum et al. 1982), chance events (Ball 1980), catastrophic events (Craighead and Gilbert 1962), and historical factors (van der Valk 1981) are also important in determining zonation.

There have been a number of studies on the effects on high marsh vegetation of activities related to mosquito control. Most of these, however, have dealt with ditching, rather than impounding, and their results are contradictory. Some studies report a shift to drier conditions with a concomitant invasion of the high marsh by upland species (Daigh et al. 1938, Daigh and Stearns 1939, Miller and Egler 1950). Other studies report a shift towards conditions more typical of the low marsh (Travis et al. 1954, Shisler and Jobbins 1977). A third group of studies report no significant change due to these activities (Taylor 1937, Headlee 1939, Ferrigno 1961). Ball (1980) reports an increase in red mangrove cover in areas ditched for mosquito control in Biscayne Bay, while several authors have reported various degrees of damage to mangroves due to improper diking and impounding (Breen and Hill 1969, Odum and Johannes 1975, Patterson-Zucca 1978, Lugo 1981). In Florida, the general consensus appears to be that impounding in mangrove areas favors the spread of red mangroves at the expense of black mangroves, white mangroves and other high marsh species (McCoy 1969).

The importance of the low marsh in the overall dynamics of the coastal zone has been recognized for a long time. The high marsh, however, was once considered by many (particularly by those wishing to develop it) as real estate with little ecological value. Recent studies, have demonstrated that the high marsh provides many of the same services as the low marsh, as well as many others that are qualitatively and/or quantitatively different and just as important to the overall health of the estuarine ecosystem (Heald 1969, Lugo and Snedaker 1974).

Below we report on vegetation data gathered at the study site since the start of the project.

METHODS

Vegetation cover on the experimental and control marshes was monitored along 1200-foot transects established at each location (Figure 1). Each transect was divided into 12 100-foot sections and five quadrat locations were chosen along each section. The distance along a section and the distance and direction from the transect line of each quadrat were determined using a random number generator (Fig 2). At each location, an estimate of percent cover by each species on a 1/4 meter^2 area was obtained with the help of a 1/2 square-meter frame that was subdivided with heavy wire into 16 equal sections. A total of 60 such estimates were obtained along each transect every 3 months from 1982 to 1985, and every 6 months thereafter.

During July of 1986, 20 additional quadrat locations were randomly selected at each site to monitor the effects of pumping on the vegetation (Fig. 1). These stations are being visited bi-weekly and the percent cover by each species, as well as the percent of each species showing signs of damage are being recorded. Photographs of each of the quadrats at the experimental site were taken during the initial visit.

We also measured the growth and establishment of mangroves in the experimental and control marshes. A total of 108 mangrove seedlings were marked initially at the experimental site and 100 at the control. In the experimental cell, 22 red mangroves, 73 black mangroves and 13 white mangroves were marked. The corresponding numbers for the control are: 28 reds, 47 blacks, and 25 whites. These proportions approximate the frequency of each species at each location. During June of 1986, 49 additional mangrove seedlings were marked at the experimental site to compensate for mortality during the previous years and to bring the number of trees back to 100.

RESULTS

Cover

At IRC #12 there has been little change in total % cover by 'floor' species (Salicornia virginica, S. bigelovii, and Batis maritima) since 1982, except for a drop in cover during the fall of 1982 (Figure 3A). The dips in the % cover curves for floor species evident during the winters are mainly due to the disappearance of the above-ground parts of _S. bigelovii_, which is an annual species. Total cover by 'canopy' species (_Rhizophora mangle_, _Avicennia germinans_, and _Laguncularia racemosa_) at IRC #12 has changed very little and has remained low throughout the study period (Figure 4A).

At SLC #24, however, cover by canopy species increased significantly during 1982 - 1986 at the expense of the floor species, which showed an irregular decline from April 1982 to December 1984 (Figures 3A & 4A).

Figures 5A - 10A show the patterns of % cover through time by the individual species. _S. virginica_ showed an overall decline at both sites since the start of the study (Fig. 5A). Cover by _S. bigelovii_ declined at both sites from April to November of 1982 and remained relatively low thereafter except for a sharp increase at the experimental cell during the summer of 1985 (Fig. 6A). _B. maritima_, on the other hand, showed increases in coverage during the spring and summer of 1983 and 1984 at IRC #12, and during the fall of 1983 and spring of 1984 at SLC #24, but returned to levels close to the original ones after December 1984 (Fig 7A).

As previously mentioned, cover by all mangrove species at IRC #12 has remained close to 0 since 1982 (Figs. 8A - 10A). At SLC #24, _Rhizophora mangle_ increased considerably from 1983 to 1984 and declined sharply after August 1985 (Fig. 8A), _Avicennia germinans_ has increased steadily since May 1983 (Fig. 9A) and _Laguncularia racemosa_ increased from 1983 to 1984, decreased during the winter of 1984, and has been steadily increasing in coverage since then (Fig. 10A).

Table 1 shows the results of two-way analyses of variance for changes in % cover by the various species along the transects. The data are the diferences in cover from July 1982 - August 1983, August 83-August 84, and August 84 - September 85. These data have been standardized to changes per 30-day period to compensate for slight differences in elapsed times between samples at the two sites and then subjected to an angular transformation to stabilize the variance.

The results indicate that for floor species there were significant differences between sites and between dates, and also significant interactions between the two factors. The site-date interaction makes it difficult to interpret the individual main-factor effects. It is more informative at this time to examine the pattern at the individual sites; we will postpone further direct comparisons of the effects of the two factors until a more complete analysis can be performed.

The results of the analyses for canopy species is more straightforward. There were significant differences in changes in cover along the transects at the two sites for red and black mangroves and significant differences between dates for white mangroves. The only significant date X time interaction was for white mangroves. Inspection of the data indicate that the significant effects of site are due to much greater increases in the cover of red and black mangroves at the control site than at the experimental (Figs. 8A and 9A). The white mangrove data indicate a slight increase at the control site from 1982 to 1983, a significant increase from 1983 to 1984, and a decrease from 1984 to 1985. At the experimental site, cover by this species remained relatively constant and low throughout (Fig. 10A). The sharp decrease of this species at the control site during the winter of 1984 resulted in a non-significant overall effect of site, whereas the differences in dates (increase in from '83 to '84 and decrease from '84 to '85) resulted in a significant effect of date. The interaction term simply reflects the fact that the effects of date were significant at one site (control) but not the other.

Frequency.

The patterns of changes in frequency along the transects resemble only partially those described above for cover (Figs. 3B - 10B). S. virginica dropped in frequency at the experimental site during the fall and winter of 1983 and partially recovered thereafter, whereas at the control site this species showed a steady decline throughout the study (Fig. 5B). After an initial decrease in 1982, S. bigelovii has shown an increasing trend at both sites, with the sharpest increases evident during the summers of 1984 and 1985 (Fig. 6B; but see "Effects of Pumping", below). Batis maritima also showed similar patterns at both sites; there were increases in frequency during most of 1982 at both sites and during the summer of 1984 at the control, but corresponding decreases during the intervening months resulted in little net change in frequency during the study period (Fig. 7B).

The patterns of changes in frequency by mangroves through time do resemble those of changes in % cover except for a relatively lower peak in frequency by white mangroves at SLC #24 in August 1984, and a smaller drop during the fall-winter of the same year (Figs. 8B - 10B).

Analysis of the differences in frequency of the various species in the individual quadrats within each transect do not always reflect the general patterns for the transects (Tables 2 & 3). Although there is often good correspondence between quadrat and transect-wide changes, many significant differences at the quadrat level are not reflected at the transect level (see below).

Mangrove Growth and Mortality.

From 1982 to 1985 there were definite and consistent yearly patterns of growth by the marked mangrove seedlings at both sites (Fig. 11). Growth rates were highest during the summer, decreased during the fall to winter minima, and then increased again during the spring. The growth rate curve for all mangrove species at IRC #12 were lower than at SLC #24, particularly during the summer peaks.

Direct comparison of mangrove growth rates at the two impoundments confirm the patterns observed at the individual sites. The higher growth rates exhibited by mangroves at the SLC #24 are significantly different from those at IRC #12 during most sampling dates. If one pools all species together these differences are significant for all sampling intervals (Table 4).

Survival of mangroves was significantly lower at the experimental site than at the control. This is true for overall mortality of all species since the start of the study (Fig. 12), and for mortality during most individual sampling intervals after

1983 (Table 5). A notable exception occurred during the March - October 1985 interval when 31% and 7% mortality of red and black mangroves, respectively, was observed at SLC #24 whereas no mortality was observed at IRC #12. The red mangrove mortality at SLC #24 during this single interval was significantly higher than the total since 1982 (arcsine test; $Ts = 2.331$, $p = 0.02$).

Effects of Pumping.

Close to 50% of the *Salicornia bigelovii* at IRC #12 showed signs of damage (browning of stems and leaves) 23 days after the onset of pumping (June 19, 1986, Figure 13A). Little damage to *Batis* or to *S. virginica* was evident at that time, nor was there evidence of damage at SLC #24. By the 36th day (July 2) almost 100% of the *S. bigelovii* showed evidence of damage and a significant proportion of the plants had died and disappeared (which caused the dip in the % damage curve between days 35 - 40, Figure 13A). During this time, water levels in the impoundment had decreased slightly due to evaporation (Figure 12). After about 40 days, water levels at both sites began to increase due to rainfall. Subsequently, damage to *S. virginica* at both sites and to *B. maritima* at IRC #12 started to become apparent. The rise in water level peaked after about 60 days, at which time low-level damage to *B. maritima* became apparent at SLC #24 and a significant increase in damage at IRC #12 was observed. A second increase in the rate of damage to *S. bigelovii* after 100 days at SLC #24 also correlates with an increase in water levels at that site (Figs. 12 & 13).

DISCUSSION

The overall patterns uncovered so far indicate that the initial response of the marsh vegetation to re-establishing the connection between IRC #12 and the lagoon was the establishment of Salicornia spp. and Batis in the marsh. Although this project was started after this initial recolonization, the patterns can be recognized by comparison of historical photographs with more current ones, and also from previous reports of conditions in this marsh (Harrington & Harrington 1961, 1982). This recolonization was rapid during the first two years, but has proceeded much slower than expected since then.

Both within-site, and between-site comparisons of the transect data indicate that temporal effects (i.e. between-years) had a significant influence in the observed patterns of change in % cover of floor species, whereas site had a significant effects on canopy species. The results of some comparisons, however, are complicated by significant time-site interactions. The inconsistencies observed when comparing net frequency changes along the transects with those obtained within the individual quadrats exemplify the complexity of the vegetation dynamics at the site. This observation indicates that at any one time, a species may have been increasing in some quadrats and decreasing in others. The balance of these changes determined whether a net increase, decrease, or no change was recorded for a given interval on a transect-wide basis.

The poor performance of mangroves at IRC #12 is not easily explained, particularly in view of their increase in cover at the control site during the same interval. One possible explanation may be a dearth of propagules, but the data indicate that even established seedling do poorly at this site. Unfavorable physical conditions may be a more plausible explanation. This would mean that conditions in the marsh have changed considerably because historical data and photographs and the ubiquity of dead trunks of black mangroves indicate that this species was common in the marsh in the past. It is possible that high concentrations of salt accumulated in the marsh soil at IRC #12 during the years that the impoundment was unmanaged. We have observed high water salinities at this site after heavy rains have flooded previously-dry areas, a fact that lends some credence to the above speculation. Studies of soil chemistry would be a valuable addition to our growing knowledge of this site.

The proliferation of all species of mangroves at the control site is also puzzling at first since the most common situation in this region is for closed impoundments to be dominated by red mangroves. A possible cause for the observed phenomena emerged during November - December 1984 when a tropical storm moved through central Florida, dumping large amounts of rain on the area and producing extremely high water levels in the Indian River Lagoon. The water level of the closed cell rose dramatically during the storm, and would have remained high for at least several weeks if the St. Lucie Co. Mosquito Control District had not helped to drain the marsh through culverts hastily installed for that purpose (see below). A 15" culvert was installed first, but this had little effect upon the marsh water level and was replaced with a 30" culvert.

The level and duration of flooding at this site would have kept most mangrove pneumatophores totally submerged for periods that would have caused considerable damage to black and white mangroves (Provost 1974). To illustrate the relation between water levels during this storm and average pneumatophore height, we randomly selected fifty black mangrove pneumatophores, measured their lengths above the marsh surface and corrected these measurements for site elevation. The results are shown, together with the water levels during and after the storm, in Figure 14. It is evident from the figure that most pneumatophores would have been totally covered during the storm period (pneumatophore elevations are not exact since the site elevations had to be measured indirectly by comparing the water level at the pneumatophore locations with a nearby water level datum; they should be correct to within 1 - 3 cm).

Thus one can hypothesize that storms such as the Nov 1984 one could be responsible for the demise of black and white mangroves in closed impoundments. Even with the efforts of the St. Lucie County Mosquito Control District, some flood damage was evident at the control site (pers. obs.). These storms are quite frequent in Florida (two such storms in the fall - winter of 1985 caused the impoundment water levels to overtop the dike (Doug Carlson, pers comm.). and could slowly eliminate most black and white mangroves from closed impoundments, leaving only red mangroves, with their high, arching prop-roots to dominate the landscape.

It is apparent that the level of pump-induced flooding at

IRC #12 caused significant damage to Salicornia bigelovii, with complete disappearance of this species observed about 85-90 days after pumping. Damage to the other marsh floor species was less drastic, but still significant. At the control site, there was some damage to S. bigelovii, but this may have been a result of the normal cycle of this species, accelerated somewhat by a rise in the water level due to rainwater which was not released due to the closed nature of this impoundment. This was probably also the cause of the moderate damage to S. virginica and the minimal damage to B. maritima observed at that site. It should be noted that the correspondence between water level and vegetation damage evident in Figures 12 & 13 is probably tighter than the figures show since mean values were used in the figures. Correlation and or concordance analyses of these data on a quadrat-by-quadrat basis will be part of the forthcoming statistical treatment of these data. It may be that the soil salinity argument presented above may also be at work here since other impoundments are routinely flooded to equal or higher levels without the adverse effects to the marsh vegetation observed here.

PART THREE - ZOOPLANKTON DYNAMICS

INTRODUCTION

Compared with other estuarine areas, there is relatively little information about the zooplankton communities of coastal wetlands and of very shallow estuarine habitats, particularly from tropical and sub-tropical coasts (Odum _et al_. 1982). One factor contributing to this dearth of data is the difficulty of sampling in such shallow areas. In these habitats use of many conventional types of gear, such as unsupported circular plankton nets, usually results in contamination of the samples with substrate material and in severe clogging (Cuzon du Rest 1963, Barnett _et al_. 1984). Clogging also occurs because the water column in such areas often carries a heavy load of suspended particles (Barlow 1955, Barnett _et al_. 1984). Furthermore, the substrate is usually extremely soft thus making it difficult to manipulate conventional gear without great disturbance to the areas being sampled.

This study represents a first attempt to characterize the zooplankton fauna of salt marsh impoundments under different management regimes. In the METHODS section below, we report on techniques that we developed for sampling zooplankton from shallow salt marsh and mangrove forest habitats, as well as from very shallow areas ($\simeq$ 0 - 1.5 m) of the Indian River Lagoon in east-central Florida.

METHODS

Our sampling equipment consisted of a combination of gear, including pumps, floating nets, and hand nets. The hand nets were simple rectangular 63u-mesh nets supported by metal frames and attached to 1.52m poles. Hand nets were used only to obtain qualitative (presence-absence data) samples from very shallow ponds in the interior of the marsh (Fig 15).

Pump Sampling Apparatus

The pump samplers were designed to maximize filtering area and to provide temporary storage for large volumes of water to prevent overflow while filtering.

Samples were collected with a 5.08 cm pump driven by a 2 hp gasoline engine. The intake hose (5.08-cm Canaflex) was attached to the pump, and the mouth to a 2-m pole with a styrofoam float near the end. This allowed the operator to maintain the mouth of the hose in constant vertical and horizontal motion while sampling, with little disturbance to the substrate (Fig. 15B).

The outflow was filtered in PVC cylinders 1.22 m high and 25.4 cm in diameter (Fig 15C) whose walls were perforated with numerous holes of various sizes covered with either 202u or 63u plankton netting (Fig 15D). Samples were collected at the bottom of the cylinders in removable screens of the appropriate mesh size (Fig 15E). A splashguard fitted on the top of each cylinder prevented sample spillage; two baffles inside the cylinders distributed the water stream to prevent damage to the lower collecting screens, and a coarse metal screen on top of the baffles trapped large pieces of debris that might have damaged the side or bottom screens.

For each sample, the outflow hose was maintained in place for a timed interval. Filtered water was collected in buckets placed adjacent to the cylinders and was used to wash organisms attached to the inner walls to the bottom screens. The screens were then removed, and their contents washed with distilled water into pre-labeled glass jars. A solution of 10% buffered formaldehyde and rose bengal (100 mg/l) was then added to each jar for sample staining and preservation.

The pump flow rate during each sample was calculated by measuring the amount of time required to fill a container of known volume to overflowing (Barnes 1949). This was done immediately before, and immediately after each sample; the mean of the two measurements was used to calculate pump flow rate, sample volume, and plankton density.

Floating Nets.

The configuration of the plankton nets minimized their vertical profile while maintaining an adequate filtering surface. They are variations of the compressed - mouth, floating net arrangement (Zaitsev 1961, Ellerstsen 1977, Schram et al. 1981), modified for very shallow sampling and portability. We found that a net with a rectangular mouth tapering to a conical cod-end worked best for these purposes. We attached the net (91.44 cm x 20.32 cm mouth, 167.64 cm long, Fig 15F) to a frame made from PVC pipe, and supported the arrangement with styrofoam floats so that when towed the mouth of the net floated just under the water surface (Fig. 15G). The mouth end of the frame was hinged to allow folding for transport and storage. A General Oceanics Model 2031 flowmeter was installed inside the mouth of each net. At the cod end of each net we installed collecting vessels with screens of 202u or 63u (Fig 15H). As with the pump samples, 202u and 63u nets were used during the study.

For each sample, the nets were hand-hauled along a pre-measured transect. Upon arrival at the transect's end, the net was removed from the water, its sides were rinsed from the outside, and the collecting vessels removed. The contents of the vessels were processed as those of the pump collecting screens. Actual volumes filtered were calculated from the flowmeter readings using standard equations. Filtering efficiencies were determined by dividing the actual volume by a theoretical one computed from net dimensions and length of tow.

STUDY SITES

Sampling sites were selected at the following locations (Figure 16): Mole Hole - a small shallow pond 0.3 - 1.2 m in depth, at the NW terminus of the perimeter ditch in IRC #12; Culvert Station - in the IRC #12 perimeter ditch near the SW culvert (depth 0.3-1.5 m); Control Station - in the perimeter ditch of SLC #24 (depth 0.5-1.5 m); Lagoon - in a shallow flat in the lagoon immediately west of the marshes (depth 0.5-1.5 m).

SAMPLING METHODS

Sample Collection

Samples were collected on a bi-weekly basis at each of the sites. At the Perimeter Ditch, Control, and Lagoon sites one sample was collected with each of the following: 63u pump, 202u pump, 63u net, and 202u net. At Mole Hole, only pump samples were taken since this site is too small for sampling with the nets. A floating net sample consisted of a straight-line tow of 61 m. Pump samples with 202u and 63u mesh sizes were of 10 and 2 minutes duration respectively. All samples with the same type of gear (net or pump) were collected on the same day, but at least 24 hrs. were allowed to elapse between pump and net samples at the same site.

Sample Processing.

In the laboratory, each preserved sample was washed with distilled water through a 63u sieve. Any large organism present in the sample (e. g. adult fish, large insects, etc.) were removed, washed over the sieve with 70 % ethanol, and stored in 70% ethanol. The rest of the sample was placed in a glass graduated cylinder and diluted in steps to volumes from 0.100 to 2.00 l. The size of the subsample and the final dilution varied depending upon the richness of each sample (Newell and Newell 1963, Carter and Dadswell 1983). The diluted sample was then aereated and mixed, taking care not to create currents that could bias the procedure by sorting the organisms according to size.

Subsampling was carried out immediately after mixing. A 1 - 2 ml subsample was obtained from the diluted sample with a Hensen-Stempel pipette. This subsample was placed in a Bogorov counting tray and spread evenly with 70% ethanol. All organisms in the subsample were counted and identified to the lowest taxonomic group possible. After counting, the subsample was returned to the original sample and the total volume was adjusted back to the original with 70% ethanol.

The process of mixing and subsampling was repeated a total of five times per sample. The density of each taxon was then calculated for each subsample, and the mean of the five replicates was used as the taxon's density for the sample.

Gear Performance.

Preliminary Tests and Filtering Efficiencies. To check the operation of the nets and flowmeters we ran several tests at the Lagoon station. In one series (1 - 3, Table 6), we installed one flowmeter in its designed location inside the mouth of the net and a second one on the outside, attached to the frame. The second series (4 - 5, Table 6) compared the efficiencies calculated from flowmeters installed side by side inside the mouth (with and without nets). The flowmeter readings were little influenced by the frame structure when inside the net (3 and 5, Table 6). As expected, some interference from frame-net turbulence was observed when the meters were located on the outside (1 & 3, Table 6). A moderate loss of efficiency, probably resulting from clogging of the 63u net (Smith et al. 1968) was observed in the 30.5 m tows, and a severe loss in the 60.9 m tows (compare run 1 with runs 2 & 4). No such effect was observed with the 202u nets. Overall, average efficiencies of the 63u nets for all samples were 7% (SD = 3.5) 6% (SD = 3.8) and 6% (SD = 3.0) for the Culvert, Lagoon, and Control stations respectively. The corresponding values for the 202u nets were 95% (8.7), 89% (8.7), and 80% (2.2).

Before the start of the study, 5 replicate samples with the 202u pumping apparatus were taken at the Mole Hole station. The average density per sample was 910 indiv./m^3, with average standard deviations per subsample (5 each) of 38.2, 58.1, 59.1, 88.9, and 55.6 indiv./m^3. A large part of this variation was due to copepod nauplii which had a coefficient of variation of 52.2

over the 25 subsamples.

Sample Volumes. Average volumes filtered with the different gear types were as follows: 202u nets: 9.69 (SD = 0.8) m^3, 202u pumps: 2.89 (0.01) m^3, 63u nets: 0.721 (0.04) m^3, 63u pumps:0.58 (0.002) m^3. As with the nets, the bottom and side screens of the 63u cylinders usually clogged before the prescribed two minutes of pumping had elapsed. When this happened, the pump and timer had to be stopped to prevent overflowing and the screens had to be cleared by tapping them from the outside for several minutes. Only after all the water in the cylinder had filtered through, could pumping be resumed until the full 2-minute sample was completed. Clogging of the 202u screens was infrequent and the full 10-minute interval could usually be pumped without interruption.

Faunal Similarity.

To get an indication of the taxonomic correspondence between samples collected with pumps and nets of the same mesh size, we computed two similarity indices; Jaccard's qualitative similarity index (JS) and Czekanowski's quantitative index (CZ), between contemporary samples collected at the same location. Jaccard's index gives an indication of the similarity in the identities of the taxa in the two samples and is not influenced by differences in the abundance of taxa in the two samples. Czekanowski's index, on the other hand, takes into account not only the species identities, but also their relative abundances; its value can be overly influenced by a single large discrepancy in the abundance of a taxon between the two samples. We chose this index, however, because of its linear correspondence with actual sample overlap (Bloom 1981). Both indices are non-probabilistic, and as such are sample size dependent (Simberloff 1978). This dependency, however, should have little influence on our results since the samples being compared here usually had similar numbers of taxa.

As expected, the values of CZ were generally lower than those of JS (Table 7). This resulted from the aforementioned influence on the index of large differences in abundance of one or a few taxa between the two samples. In general, the similarity between the pump and net catches at the same site was intermediate to low, ranging from 0.263 (CZ) for the 202u gear at the culvert station to 0.672 (JS) for the 63u gear at the same station. In contrast, replicate samples with the same gear type yielded catches with 0.717 (JS) similarity (Table 7).

Plankton Density.

Overall, densities of organisms in the samples were consistent between sites, between gear types, and between different mesh sizes. There was a high correlation in mean densities per taxon between data obtained with the different gear types (Table 8), but there were some major differences in total density between collections on some sampling dates (Table 9). Total density estimates, however, were much higher in pump and net samples collected with the 63u mesh gear than with the 202u gear. Average overall densities per sample were 5,549 and 2,878 indiv./m^3 for 202u pump and net samples, respectively whereas the corresponding values for the 63u gear were 403,907 and 279,277 indiv./m^3. This was partly due to undersampling of the smaller organisms by the 202u gear, and to the relatively low volumes filtered with gear using 63u mesh screens which resulted in very high conversion values (from mean number of individuals per sample to density per cubic meter) and thus, yielded inflated density estimates.

Discussion.

No single method is totally adequate for obtaining representative samples of the plankton community of an area. On the other hand, logistic, time, and financial constraints usually preclude the use of a large number of techniques in any given study (Fraser 1968). The particular choice of methods utilized will depend upon the aim of the study, the physical conditions existing in the area of interest, and the resources available to the investigator.

Some of the major advantages of the methods described here are the ability to sample areas that cannot be sampled effectively with more conventional gear, low cost, portability, and relative ease of operation. Major disadvantages arise from the fact that sampling is possible only to a very limited depth and, in the case of the nets, that speed of tow is relatively slow.

Improper sampling of the deep layers of the water column is not a factor in areas for which these methods were designed since the water is at most only a few centimeters deeper than the effective sampling depth of the equipment. Speed of tow however, may have to be taken into consideration when evaluating results. The slow speed will likely allow escape and/or avoidance by the more actively swimming organisms in the water column. On the other hand, it may reduce the number of organisms escaping through the meshes due to distortion of the meshes and compression of organisms by water pressure (Heron 1968, Vannucci 1968), and may also reduce turbulence in front of and upstream from the net thus reducing net avoidance (Raymont 1983, Clutter and Anraku 1968).

Recent studies of estuarine zooplankton report sample sizes (i.e. volumes filtered) in the range of 1 to 6 m^3 (Barnes 1949, Barlow 1955, Johnson 1980, Williams 1984); volumes obtained with the 202u gear were equal to, or higher than the above, and were limited not by the gear itself but by the physical dimensions of the habitat. Under different conditions, both 202u pump and net sample sizes could be increased considerably if so desired. Sample volumes obtained with the 63u gear alone however, may be too small for some studies requiring accurate description of community structure of the zooplankton of an area.

If all the organisms collected with each gear type during the study are pooled, the similarity between pump and net samples is close to 70%, but comparisons of data from individual sampling dates indicate much lower similarities (Table 2). Thus, both nets and pumps appear to be necessary for proper sampling of these habitats.

There has been considerable debate over the advantages and disadvantages of different techniques for sampling zooplankton (Clutter and Anraku 1968). A combination of methods such as were used in this study usually represents the best possible compromise. Rectangular nets and various forms of pumping have been used successfully before (Barnes 1949, Fulton 1984, 1985) and were the only workable configurations for sampling in sites such as the ones described here.

RESULTS

Number of Taxa.

In total, 68 taxa have been recovered so far from our collections (Appendix A). Figure 17A shows the total number of taxa (exclusive of fish, and macrocrustaceans) collected at each station. As expected, the Lagoon station was the most diverse (48 taxa), followed by the Culvert (43), Control (37) and Mole Hole (34). If all taxa are included, the corresponding numbers are 55, 47, 41, and 36. In total, 8 taxa were collected only at the Lagoon station, whereas 2 were collected only at the Culvert and Control, and 1 taxon was collected only at Mole Hole. Six taxa were missing only from Mole Hole collections, two from Control, and none from the Culvert, or Lagoon.

Of the six taxa missing from Mole Hole only, three were relatively rare at the other stations (Ceriantaria, Oligochate sp. A, and Argulus sp.). The remaining three taxa (Bivalve larvae, Balanus larvae, and Ascidean larvae) were relatively common at the other sites. The two taxa missing from the Control station were Sphaeroma sp. and Anomuran zoea; the former was rare at the other stations whereas the latter was relatively common.

Temporal patterns in numbers of taxa collected at the different sites are fairly consistent. Peaks in diversity were observed in the summer of 1982 (May - August depending upon the site) and minima during the spring of 1983 (April-May).

Secondary peaks in diversity were observed at some sites during November - December of 1982 (Figures 18A - 25A). There is some indication that the spring-summer peak observed in 1982 may be repeated during the summer of 1983, but a definite conclusion will have to wait until the remaining samples are processed.

Density.

Overall, highest densities of organisms were collected at Mole Hole, followed in descending order by the Lagoon, Control, and Culvert sites (Figure 17B). This hierarchy holds true for densities obtained from 202u and 63u collections as well as for both combined.

The seasonal patterns of density are less clear cut than those of numbers of taxa. This is partially due to the previously-mentioned discrepancies in density estimates between 202u and 63u gear. For the 202u data there were peaks in density during May - August of 1982 at the Culvert and Lagoon stations, and during April - June of 1983 at Mole Hole and Control, with a secondary peak during December of 1982 at Control (Figures 18B - 21B). The 63u data show irregular peaks from May to October of 1982 at the Culvert and Lagoon sites, from May to September of 1982 and April to June of 1983 at Mole Hole, and on December of 1982 and June of 1983 at the Control site (Figures 22B to 25B).

DISCUSSION

At least superficially, the kinds and densities of organisms captured during the study appear to be typical of shallow estuarine areas. As in most such areas, copepods are the most abundant planktonic group, with typical estuarine forms such as

Acartia tonsa, Oithona nana, O. colcarva, Ergasilus sp., Scottolana canadensis, and miscellaneous copepodites dominating the collections.

The observed patterns of total diversity indicate that the ubiquitous species-area (Arrhenius 1921)/species-isolation phenomena may also be at work here. The hierarchy in total numbers of taxa (Lagoon > Culvert > Control > Mole Hole) follows a trend of increasing site isolation and decreasing size. Although we may be stretching the classical meaning of 'isolation' by applying it to these sites, the patterns of missing species at Mole Hole and Control may justify its use, at least for heuristic purposes. A complicating factor is the fact that fewer samples were taken at Mole Hole than at the other sites, but the observed results appear to hold whether we consider all samples, or only those obtained by pumping.

One puzzling aspect of the density patterns is the fact that the smallest total density estimates were from the Culvert station. Several processes may be invoked to explain this observation. It may be that this station represents a 'transition zone' between the marsh and lagoon were few taxa maintain standing populations but many different taxa are collected because of the nearness of the lagoon-marsh connection. This area may also be a high-predation area, where predators, particularly fish, usually find refuge from receeding waters. Alternatively, it may be that certain physical parameters existing at this site either limit population increase or prevent the build-up of high population densities (i.e. by continuous or discontinuous transport to other locations). The proximity of the culvert, and the fact that many portions of the marsh drain into this area may be significant in this respect. Analysis of individual samples, as well as examination of the data from Mole Hole after installation of the culvert may help us narrow the alternatives.

PART 4 - WATER QUALITY

INTRODUCTION

Water, the pervasive and all-important medium of salt marshes and mangrove swamps is a highly variable substrate in these habitats. Whereas water quality charcteristics in the ocean depths are relatively constant, the water quality of marshes and shallow estuaries are known to fluctuate widely, with some parameters often exhibiting natural diel variations that extend into the long-term lethal range of many estuarine organisms (E.P.A. 1976). The water quality at any given location of a marsh or estuary depends, to a great extent, upon four processes: 1) sediment-water interactions, 2) land runoff, 3) direct human impact, 4) seawater inflow.

The Indian River lagoon exhibits few deviations from the above generalities. Water quality in the lagoon ranges from good to poor; the areas with the most severe water quality problems being those most impacted by human intervention (Poole 1985).

The lagunal nature of the Indian River has a significant impact upon its water quality. The major connections from lagoon to ocean, the St. Lucie, Ft. Pierce, and Sebastian inlets all occur within the sourthern half of the lagoon, and their actual flushing effect may only extend a mile or two on either side of the inlets (Ryther 1985). Likewise, three of the four major sources of fresh water, the St. Lucie and Sebastian Rivers and Taylor Creek, are located within the southern half of the lagoon. Only Turkey Creek provides direct fresh water input to the northern half of the Indian River.

Thus, overland runoff and autochtonous lagunal processes, including those occurring within the lagoon's marshes, are extremely important to the water quality of the Indian River. Modifications to the marshes and mangove forests along the lagoon can have profound effects, not only upon the specific habitats being impacted, but also upon water quality along significant portions of the lagoon.

Below we report on studies on the diel and seasonal variations of several water quality parameters in impounded marshes along the Indian River and in the surrounding lagunal waters.

METHODS

Sampling Stations.

Mole Hole: A small, shallow pond at the N.W. corner of impoundment IRC #12. It is connected to the perimeter ditch and is directly influenced by water flow through the north culvert. It is surrounded by black mangroves and *Salicornia* spp. with Brazilian Peppers also occurring on the dike side.

IR-0 - IR-20: A series of four stations on the Indian River side of the north culvert. IR-0 is located just outside of the culvert, and IR-5, IR-10, and IR-20 at 5, 10, and 20 meters respectively, in a straight line away from the culvert.

Rain Gauge: A small semi-permanent pond at the N.E. corner of IRC #12. It is surrounded by stands of *Salicornia* spp.

Pond P-3: A fairly large but shallow permanent pond located near the center of the impoundment. The vegetation near this site consists of *Salicornia* spp. and a few black mangroves. Fairly extensive barren areas and numerous black mangrove stumps also occur near this station.

Hibreed & Lobreed: 'Depressions' in flats on the east side of the impoundment, surrounded by black mangroves and barren areas. Historically, these have been areas with high and low production of salt marsh mosquitoes.

South Culvert (Imp.): At the perimeter ditch, near the mouth of the south culvert.

South Culvert (Lagoon): In the Indian River, outside the south culvert.

Control: In the perimeter ditch of the adjoining impoundment (SLC #24). This site has been totally isolated from the lagoon except for a short period when a culvert was opened to release excess water.

Sampling platforms have been constructed at the Hibreed, Lobreed, Rain Gauge, P-3, and Control stations to prevent contamination of the water samples with substrate and also to prevent the creation of ruts and/or trails by foot traffic that may influence fish movements across the marsh.

Field Methods.

All sites were visited during each sampling cycle and the following variables were measured at each site: D.O. and water temperature (Yellow Springs Model 56 D.O.-temperature meter), Salinity (Corning temperature compensating refractometer), pH (Gallenkamp pH probe), and air temperature (mercury thermometer). A water sample was also collected from each station with the exception of the South Culvert (Lagoon) site. Samples were collected 6-10 inches from the surface (closer to the surface when water levels were low) by immersion of a one-quart Nalgene bottle. If the water levels were very low, samples were collected with a hand pump.

After collection, 4 - 125 ml aliquots were extracted from each sample and stored in separate Nalgene bottles. The rest of the samples were immediately vacuum-filtered through 0.045u Gelman filters. The filtered samples were then transfered to 125 ml Nalgene bottles, fixed with 1 ml of $HgCl_2$, and stored on ice for transfer to the laboratory.

Four such cycles were carried out during each sampling (bi-weekly during the first year, and monthly during the second). Cycles started at 8:30 am, 2:30 pm, 8:30 pm and 2:30 am. (EST).

Laboratory Analyses.

All laboratory determinations except for tannin-lignin and dissolved solids were carried out on the filtered and fixed fraction of the samples using a Technicon II Autoanalyzer System. The specific methods are outlined in the Technicon Industrail Methods Manual (Technicon 1973), with certain modifications described by Zimmerman and Montgomery (1984). Below is a short description of these methods.

Ortho-phosphate: (Technicon Industrial Method 155-71W). Colorimetric determination: phosphomolybdenum blue complex, 880 nm filter. Sampling rate = 30/hr with a wash-sample ratio of 2:1. Range: 0 - 4.0 ugat/l.

Total Phosphorus: Same procedure as above after persulfate digestion.

Total Organic Phosphorus: By subtraction of ortho-phosphate from total phosphorus.

Nitrate + Nitrite: (Technicon Industrial Method 158-71W).

Colorimetric determination after reduction of nitrate to nitrite by passing sample through a cadmium-reduction column: reddish-blue azo die, 550 nm filter. Sampling rate = 40/hr with a wash-sample ratio of 4:1. Range: 0 -5.0 ugat/l.

Nitrite: Same method as above but without cadmium reduction.

Nitrate: By subtraction of Nitrite from Nitrate + Nitrite.

Ammonium: (Technicon Industrial Method 154-71W).
Colorimetric determination: blue-colored compound related to indophenol, 630 nm filter. Sampling rate 30/hr with a wash-sample ratio of 2:1. Range: 0 - 12.0 ugat/l.

Total Nitrogen: (D'Elia *et al*. (1979), Zimmerman & Montgomery (1984)). Persulfate oxydation followed by Cadmium reduction. Colorimetric determination as for nitrate & nitrite.

Tannin-Lignin: (HACH TA-3 Tanning-Lignin Test).
Colorimetric determination: blue color in 'TanniVer 3' reagent. Range: 0 - 15 and 0 - 150 mg/l tannic acid.

Dissolved Solids: (Myron L 5123T DS Meter). Direct reading. Range: multiple.

Autoanalyzer output was converted to concentrations with an RPL program for the RS/1 Data Analysis System run in Digital Equipment Corporation PRO 350 & PRO 380 computers. At least two replicates were run for each sample and the means were used as the values for each sample.

YEAR ONE DATA

As mentioned in the introduction, some very intensive 'number crunching', data manipulations, and statistical analyses will be necessary before interpretation of the water quality data is possible. The time and effort involved in such an endeavor precludes our inclusion in this report of 'preliminary analyses' of a partial data set and later repetition of the process with the complete set. Instead, we will include a graphic presentation of central tendencies and variability of the data from the first year's sampling with little discussion or interpretation. The purpose of this presentation is to give the reader an indication of the type of information that is being generated by this portion of the study.

The means for the water chemistry variables measured during the study are presented in Figure 27, and their coefficients of variation in Figure 28. It is evident from these figures that there are significant differences in many of the variables among the sites, and that some of the sites are more variable than others. It appears that Hibreed, Lowbreed and P3 will be the most deviant sites and also the most variable. It should be noted that some outlying (in the statistical sense) measurements are included in these calculations and they me be exerting a disproportionate influence on the values displayed in the figures.

PERSPECTIVE: PROJECT TO DATE

Our vegetation work illustrates the complexity of the vegetation dynamics of impounded marshes. We have learned that infreqent events, such as 10-year storms, may have profound effects upon the marsh vegetation, and that plans to quickly release excess water resulting from these events must be incorporated into any management design. We also have an indication that the marsh soil chemistry may be significantly affected by several years of 'non-management', and that the effects may be long-lasting. We have demonstrated adverse effects of pump-induced flooding which may be related to the above phenomenon.

Although still preliminary, the plankton data indicate that areas of impounded marshes can support abundant and diverse plankton populations, but that artificial structures and alterations to the marsh can have significant influence on the abundance, distribution and composition of its plankton communities. It is also evident from our data that connection to the lagoon is important in maintaining a diverse and stable zooplankton assemblage in the marsh. One of the most interesting aspects of this study will be a joint evaluation of the effects of these marsh structures, modifications and management strategies on fish and zooplankton distribution, and of the interrelationships between the two.

It is apparent by mere inspection of the water quality data that different regions of impounded marshes have different water quality characteristics. This is not necessarily a result of impounding, but our analysis will try to identify particular problem areas in the marsh and their relationship to water control structures and strategies. We will also characterize the water plume emanating from impoundment culverts, and the effects of incoming lagoon water upon impoundment water quality.

The above conclusions are, by necessity, of a generalized nature, and include only a few of the many patterns and processes that we expect to characterize after completion of the data analysis. It is obvious from this report, that a massive amount of information has been generated by all investigators since the start of this study. Even though the data being produced is extremely valuable from a purely scientific point of view, the ultimate payoff of projects such as this one has to be the development of better ways to manage salt marshes. Some reccomendations to this effect are included in this report, but the bulk of our insights will come at a latter date, after the data is thouroughly analyzed. Further advances are to be expected after the results are circulated among researchers and resource managers, who may use it to solve some very specific problems, and who will formulate their own conclusions and will develop new applications for our results.

Many valuable sampling techniques have been developed during this project and these will serve investigators faced with similar sampling problems in the future. Also, as is usually the case, this project will raise more questions that it will answer, thus pointing the way to promising areas for future research.

One shortcoming that we have all experienced during the project has been a chronic shortage of manpower. Although we have been surprisingly successful in adhering to the planned sampling schedules, keeping up with the sample processing, data mangement and statistical analysis has been impossible, even with considerable investment of time from no-project personnel.

Communication between investigators has been excellent, thanks to agresive coordination by the project manager. This has paid off in cooperation in many aspects of the project as well as in the avoidance of repetition of effort. The administrative and fiscal structure of the project, with one primary grantee and several subcontractors has also been advantageous. This arrangement has allowed for the most efficient utilization of funds, has maintained uniformity and continuity in reporting and other administrative matters, and has freed the investigators from many grant-related administrative duties. The only disadvantage of this arrangement has been a serious shortage of funds due to the fact that we are conducting several intensive research projects under a single-project funding ceiling.

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FIGURE LEGENDS

Figure 1. Map showing the location of the transects (lines & x's), and the location of the post-pumping quadrat locations (circles).

Figure 2. Scale maps of the transects. (A) IRC #12, (B)SLC #24.

Figure 3. (A) Total ground vegetation cover, (B) Total ground vegetation frequency along the transects in the two impoundments.

Figure 4. (A) Total mangrove cover, (B) Total mangrove frequency along the transects in the two impoundments.

Figure 5. (A) Mean _S_. _virginica_ cover, (B) Mean _S_. _virginica_ frequency along the transects in the two impoundments.

Figure 6 (A) Mean _S_. _bigelovii_ cover, (B) Mean _S_. _bigelovii_ frequency along the transects in the two impoundments.

Figure 7. (A) Mean _B_. _maritima_ cover, (B) Mean _B_. _maritima_ frequency along the transects in the two impoundments.

Figure 8. (A) Mean _R_. _mangle_ cover, (B) Mean _R_. _mangle_ frequency along the transects in the two impoundments.

Figure 9. (A) Mean _A_. _germinans_ cover, (B) Mean _A_. _germinans_ frequency along the transects in the two impoundments.

Figure 10. (A) Mean _L_. _racemosa_ cover, (B) Mean _L_. _racemosa_ frequency along the transects in the two impoundments.

Figure 11. (A) Mean mangrove growth per month in the two impoundments. (B) Total % mortality of red, black, and white mangroves at IRC #12 and SLC #24.

Figure 12. Mean water level at the post-pumping survey locations (A) IRC #12, (B) SLC #24.

Figure 13. Results of the post pumping vegetation surveys. (A) IRC #12, (B) SLC #24. Values plotted are means for twenty quadrats at each site.

Figure 14. Pneumatophore heights (squares) vs. water levels (circles) at SLC #24 after the Thanksgiving 1984 storm. Arrows indicate the dates when the 15" and 30" culverts were installed.

Figure 15. Illustrations of the plankton gear. (A) hand nets (B) pole-float assembly, (C) filtering cylinders, (D) side wall of cylinder showing some of the exhaust holes, (E) removeable bottom screens of the cylinders, (F) floating net mounted on its frame, (G) net under tow, (H) net collecting vessels.

Figure 16. Location of the plankton and water quality sampling sites.

Figure 17. (A) Total number of taxa, (B) total plankton densities collected at various sites.

Figure 18. (A) Numbers of taxa, (B) densities collected at Mole Hole during each sampling with the 202u gear.

Figure 19. (A) Numbers of taxa, (B) densities collected at the Culvert Site during each sampling with the 202u gear.

Figure 20. (A) Numbers of taxa, (B) densities collected at the Lagoon Site during each sampling with the 202u gear.

Figure 21. (A) Numbers of taxa, (B) densities collected at the Control Site during each sampling with the 202u gear.

Figure 22. (A) Numbers of taxa, (B) densities collected at Mole Hole during each sampling with the 63u gear.

Figure 23. (A) Numbers of taxa, (B) densities collected at the Culvert Site during each sampling with the 63u gear.

Figure 24. (A) Numbers of taxa, (B) densities collected at the Lagoon Site during each sampling with the 63u gear.

Figure 25. (A) Numbers of taxa, (B) densities collected at the Control Site during each sampling with the 63u gear.

Figure 26. Numbers of taxa collected during each sampling at the temporary ponds.

Figure 27. Mean values of physical-chemical variables recorded at the various sites during each of the four sampling cycles. (A) Air temperature, (B) water temperature, (C) pH, (D) dissolved oxygen, (E) salinity, (F) total inorganic P, (G) total organic P, (H) total P, (I) ammonia, (J) nitrite, (K) nitrate, (L) total persulfate N, (M) dissolved solids, (N) tannin-lignin.

Figure 28. Coefficient of Variation of the physical-chemical variables measured at the various sites during each of the four sampling cycles. (A) Air temperature, (B) water temperature, (C) pH, (D) dissolved oxygen, (E) salinity, (F) total inorganic P, (G) total

organic P, (H) total P, (I) ammonia, (J) nitrite, (K) nitrate, (L) total persulfate N, (M) dissolved solids, (N) tannin-lignin.

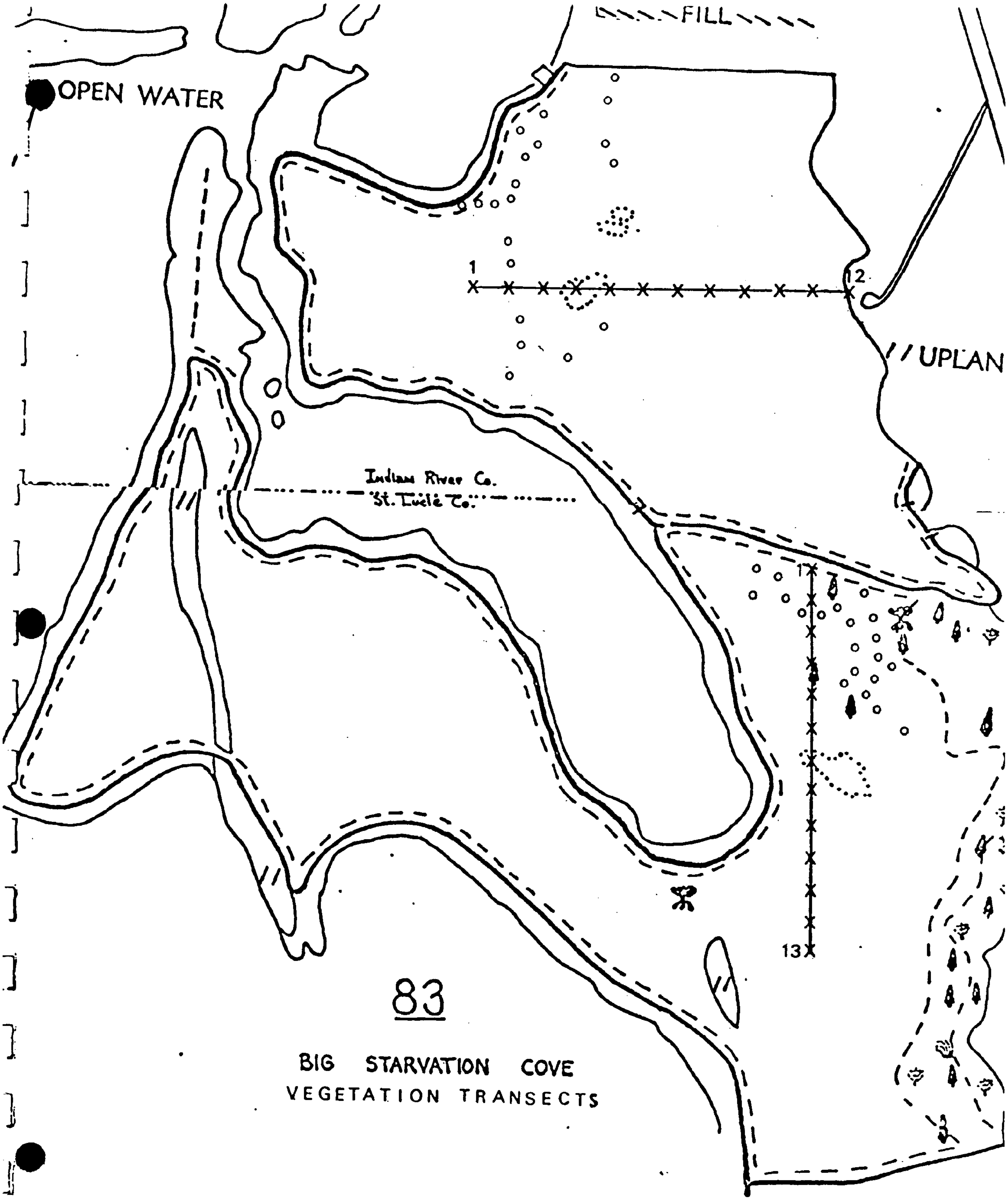

FILL
OPEN WATER
UPLAN
Indian River Co.
St. Lucie Co.
1
12
1
13
83
BIG STARVATION COVE
VEGETATION TRANSECTS

FIG 1

FIG 2A

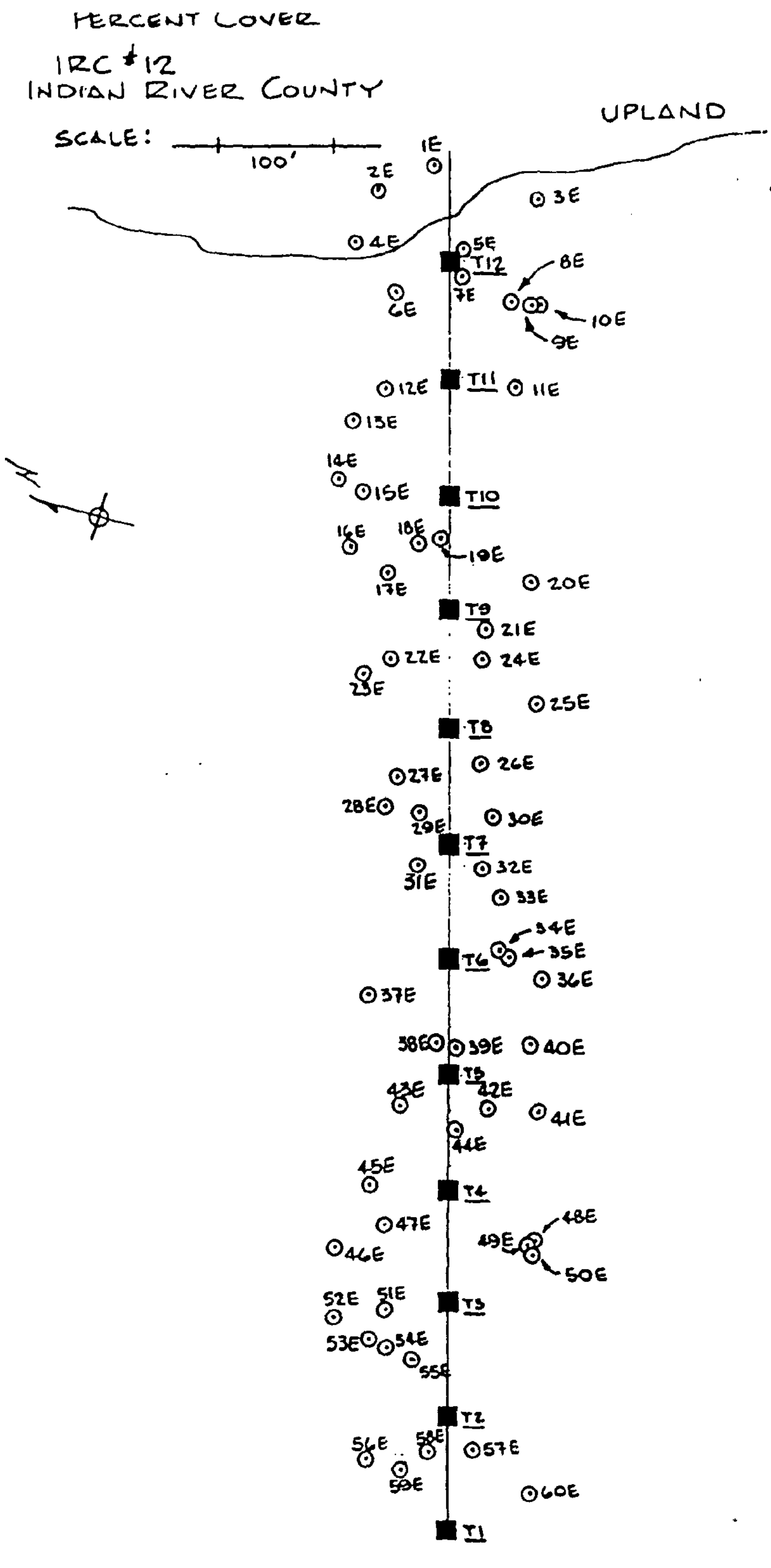
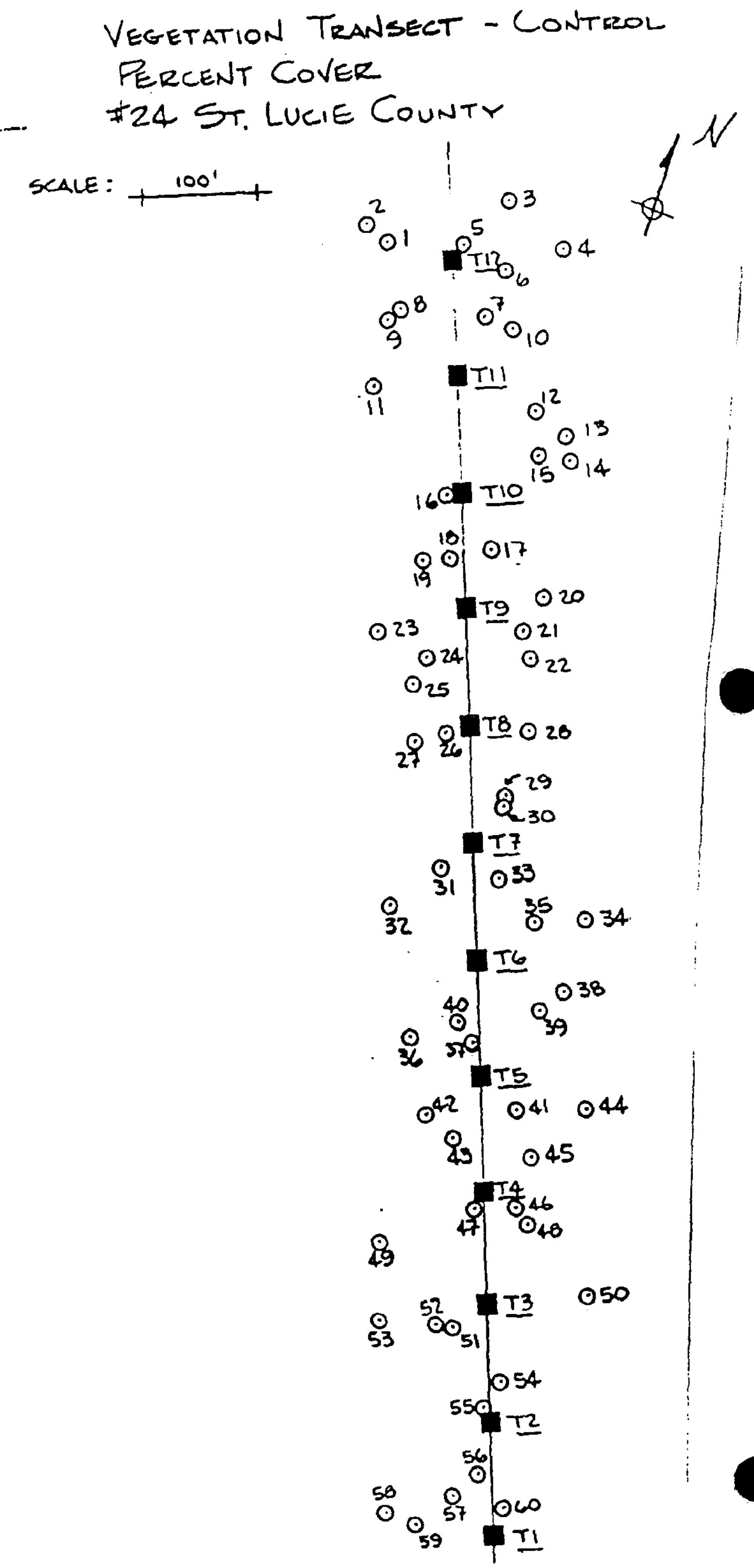
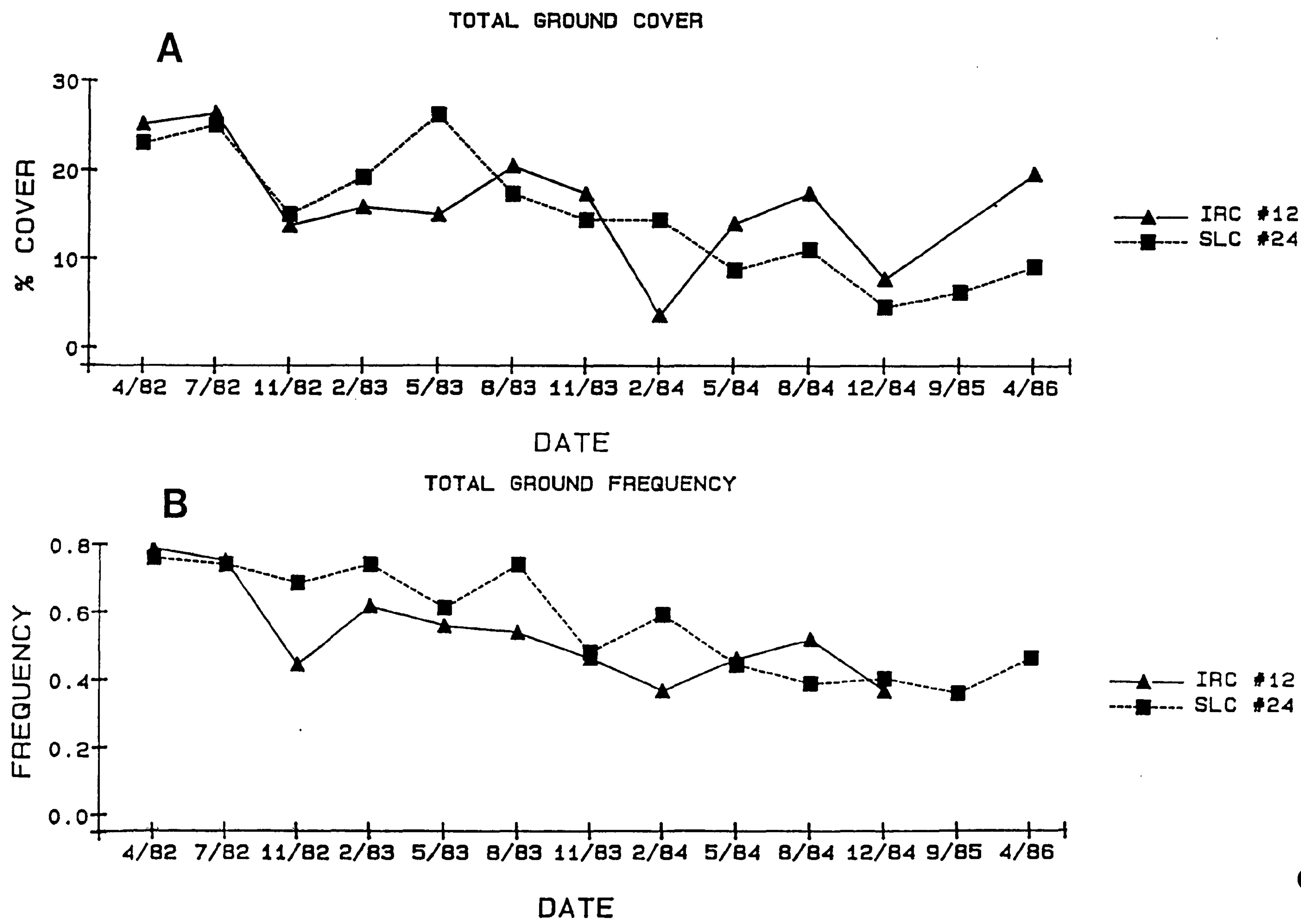
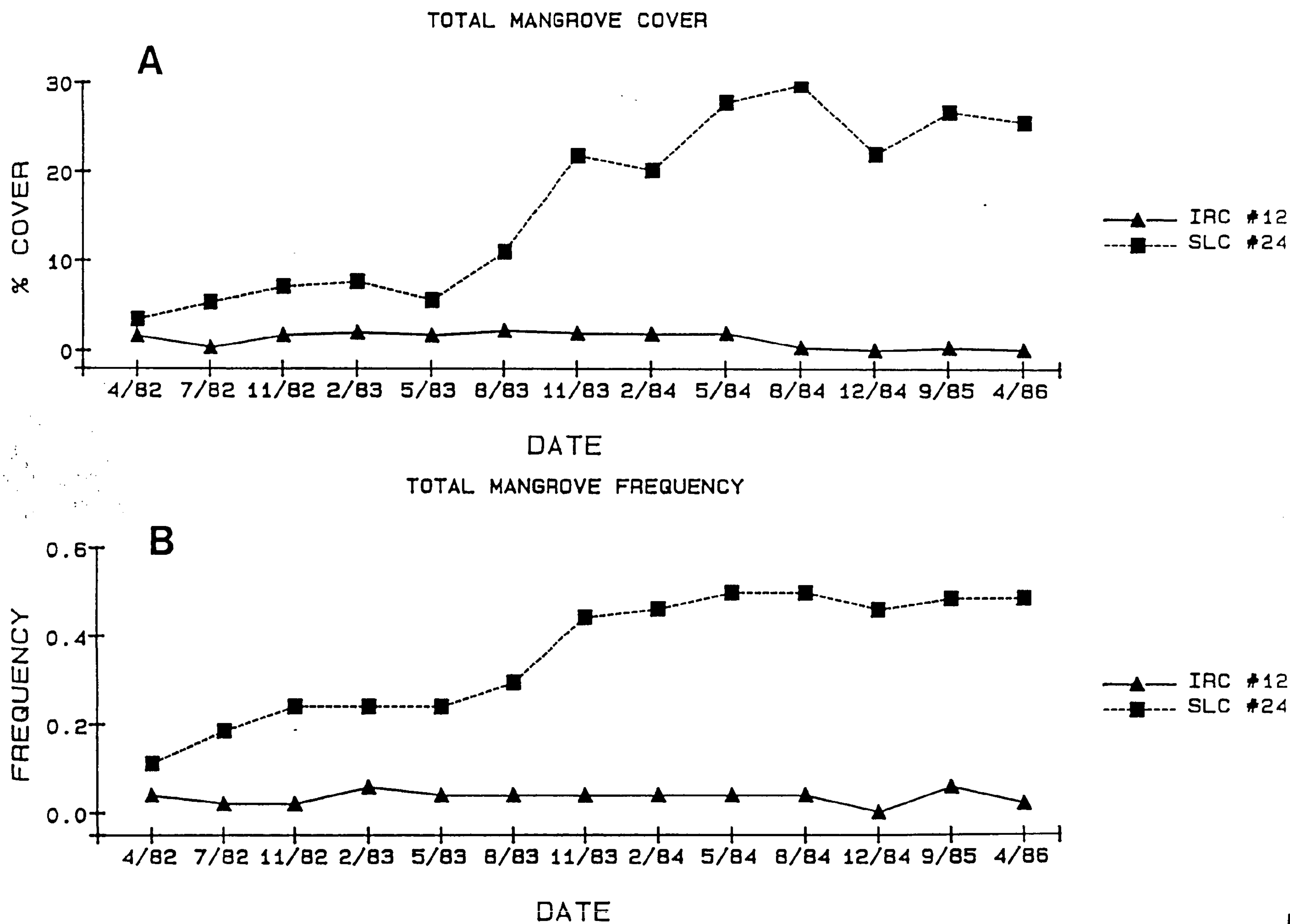

PERCENT COVER
IRC #12
INDIAN RIVER COUNTY
SCALE:
100'
UPLAND
T12
T11
T10
T9
T8
T7
T6
T5
T4
T3
T2
T1

FIG 2B

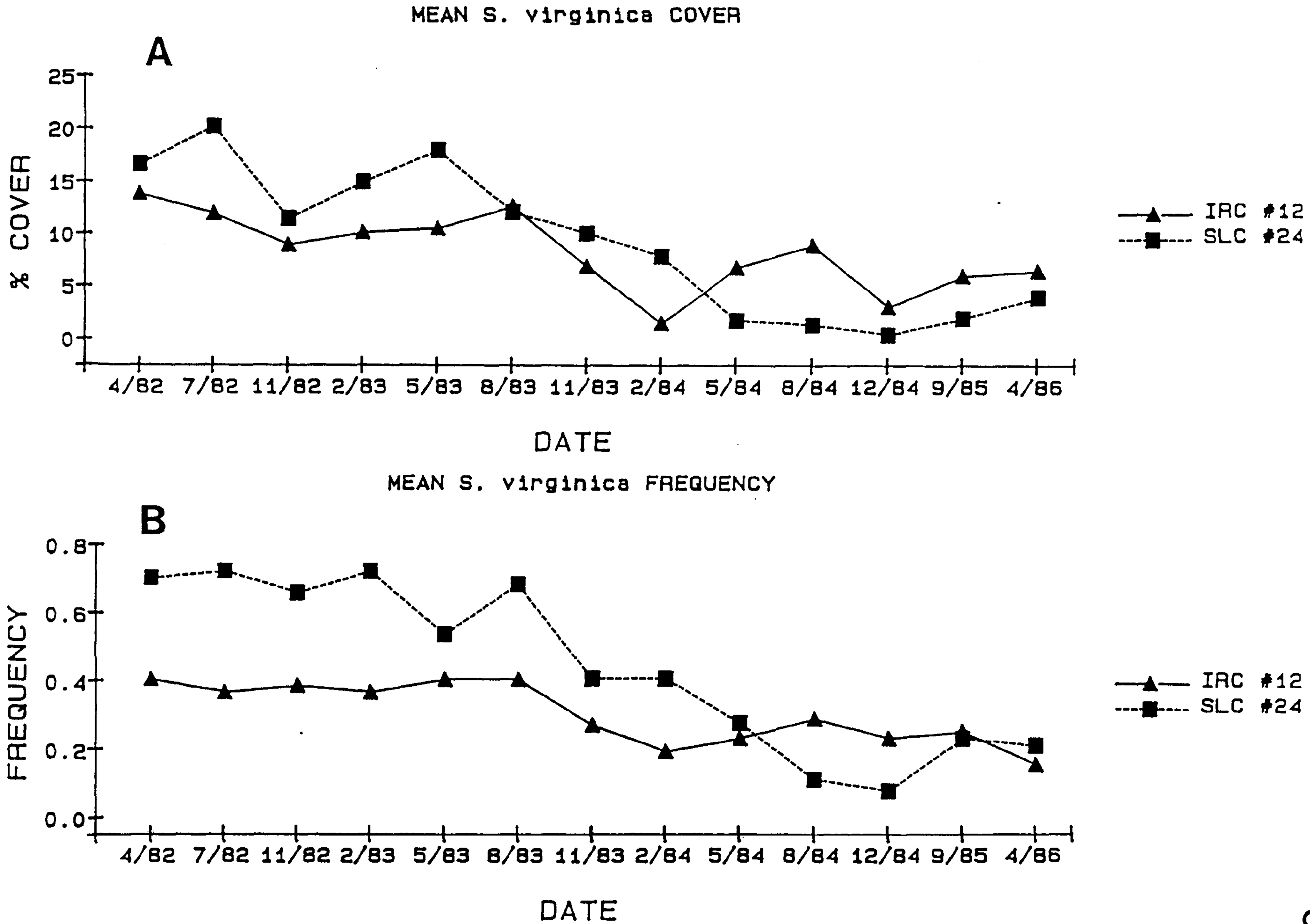

VEGETATION TRANSECT - CONTROL
PERCENT COVER
#24 ST. LUCIE COUNTY
SCALE:
100'
N
T12
T11
T10
T9
T8
T7
T6
T5
T4
T3
T2
T1


TOTAL GROUND COVER
A
% COVER
30
20
10
0
4/82 7/82 11/82 2/83 5/83 8/83 11/83 2/84 5/84 8/84 12/84 9/85 4/86
DATE
IRC #12
SLC #24
TOTAL GROUND FREQUENCY
B
FREQUENCY
0.8
0.6
0.4
0.2
0.0
4/82 7/82 11/82 2/83 5/83 8/83 11/83 2/84 5/84 8/84 12/84 9/85 4/86
DATE
IRC #12
SLC #24

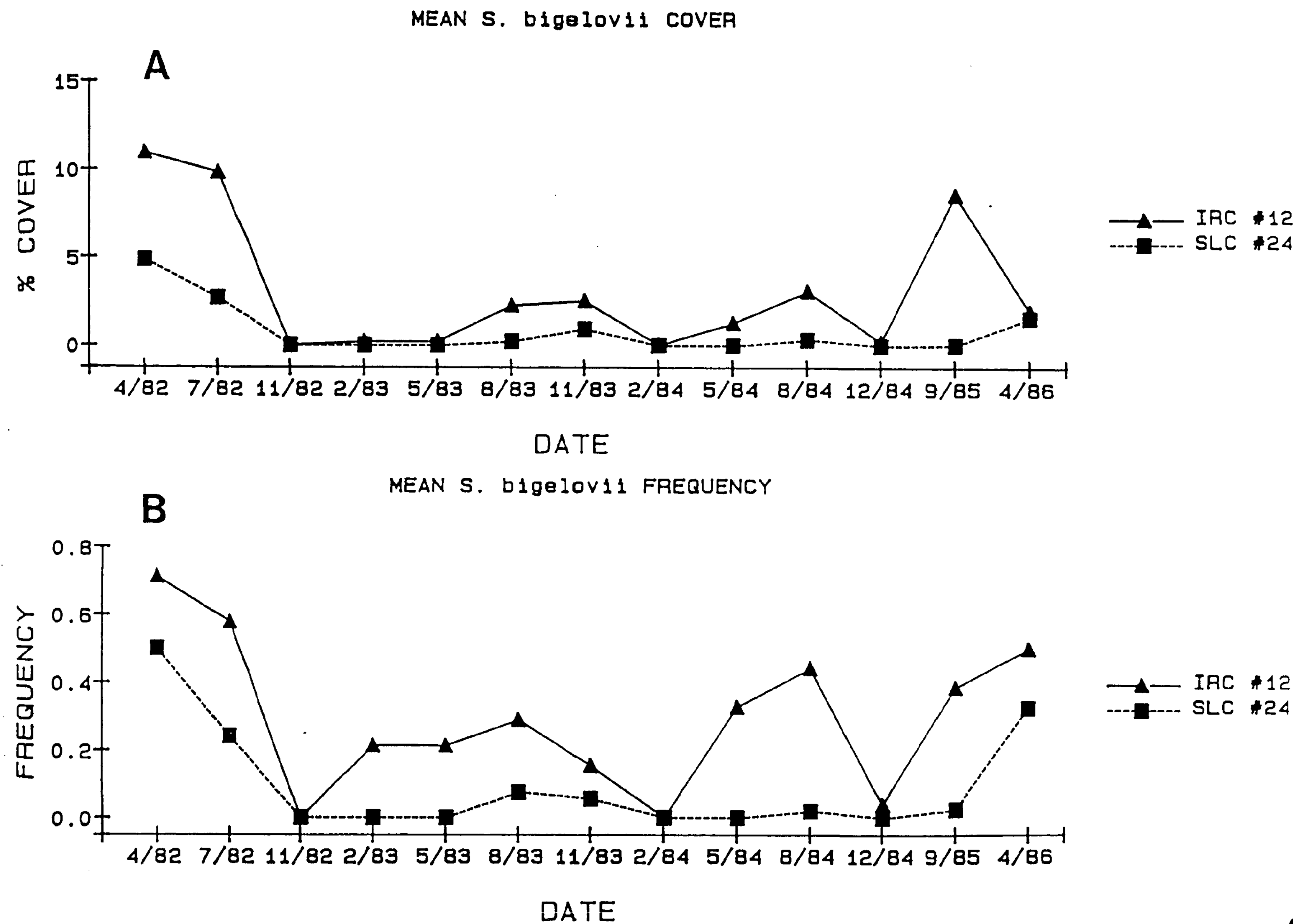
3


TOTAL MANGROVE COVER
A
% COVER
30
20
10
0
4/82 7/82 11/82 2/83 5/83 8/83 11/83 2/84 5/84 8/84 12/84 9/85 4/86
DATE
IRC #12
SLC #24
TOTAL MANGROVE FREQUENCY
B
FREQUENCY
0.6
0.4
0.2
0.0
4/82 7/82 11/82 2/83 5/83 8/83 11/83 2/84 5/84 8/84 12/84 9/85 4/86
DATE
IRC #12
SLC #24

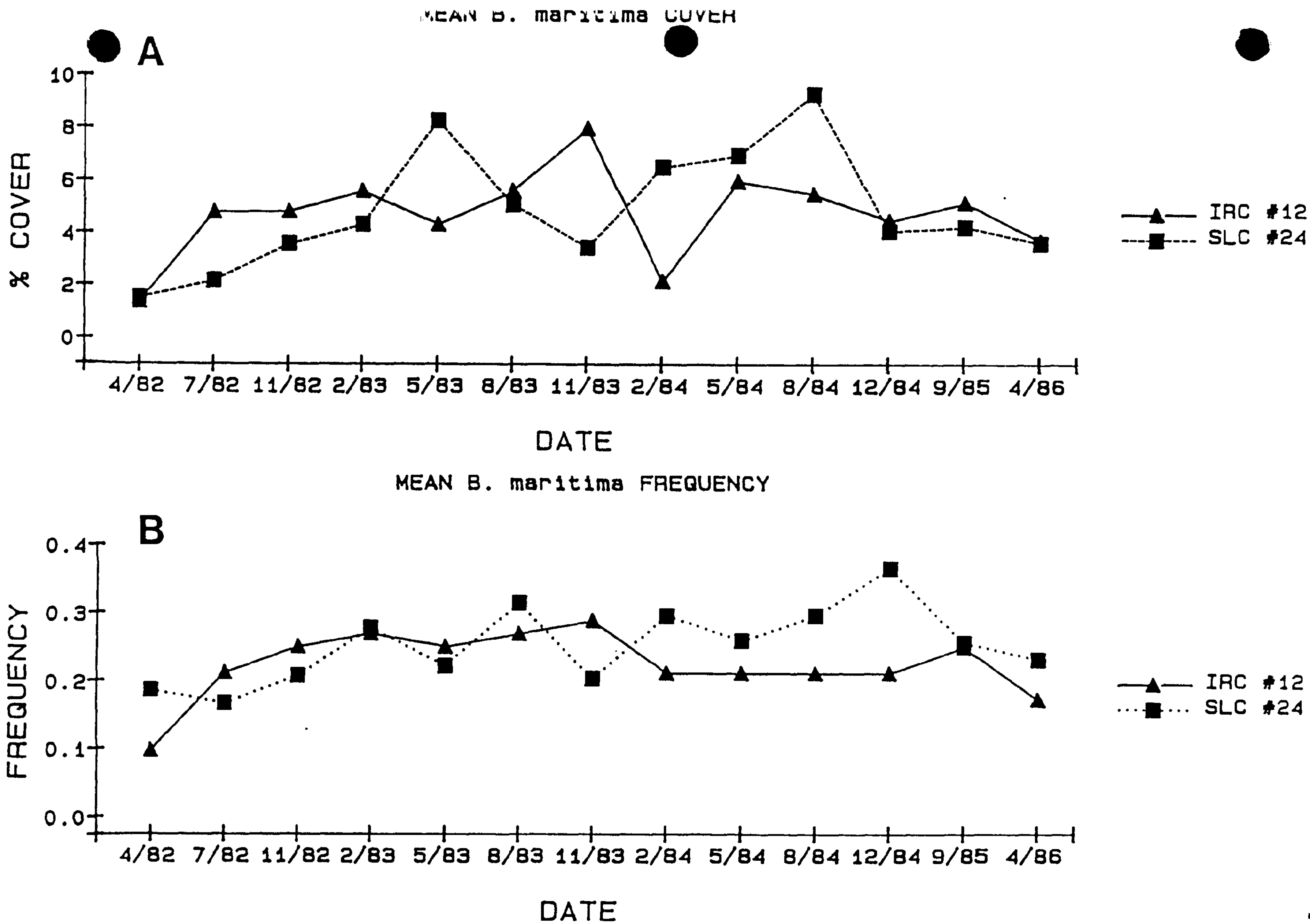
4

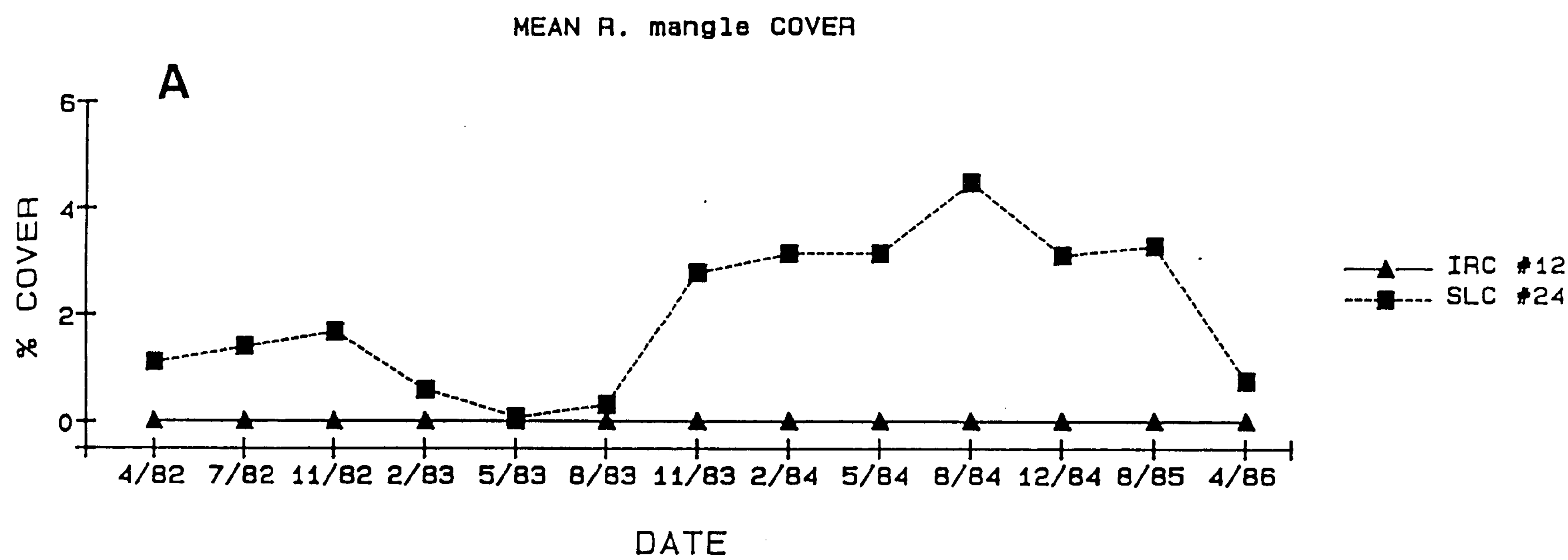

MEAN S. virginica COVER
A
% COVER
25
20
15
10
5
0
4/82 7/82 11/82 2/83 5/83 8/83 11/83 2/84 5/84 8/84 12/84 9/85 4/86
DATE
IRC #12
SLC #24
MEAN S. virginica FREQUENCY
B
FREQUENCY
0.8
0.6
0.4
0.2
0.0
4/82 7/82 11/82 2/83 5/83 8/83 11/83 2/84 5/84 8/84 12/84 9/85 4/86
DATE
IRC #12
SLC #24

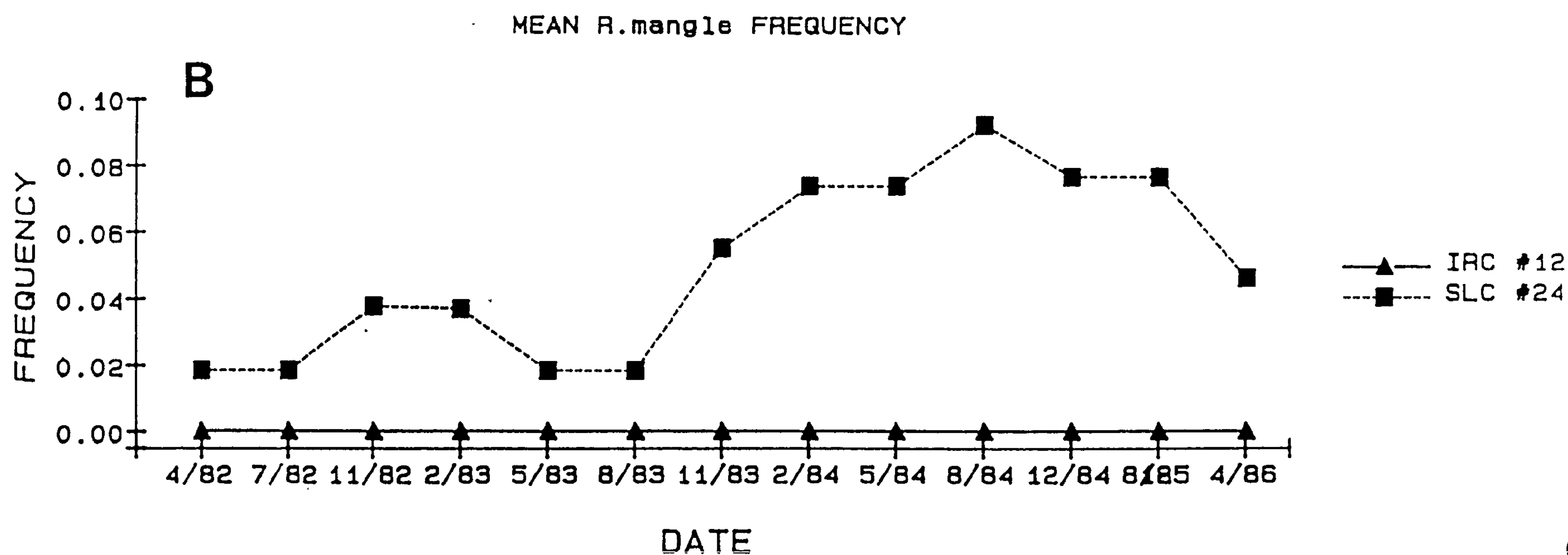
5


MEAN S. bigelovii COVER
A
% COVER
15
10
5
0
4/82 7/82 11/82 2/83 5/83 8/83 11/83 2/84 5/84 8/84 12/84 9/85 4/86
DATE
IRC #12
SLC #24
MEAN S. bigelovii FREQUENCY
B
FREQUENCY
0.8
0.6
0.4
0.2
0.0
4/82 7/82 11/82 2/83 5/83 8/83 11/83 2/84 5/84 8/84 12/84 9/85 4/86
DATE
IRC #12
SLC #24

6

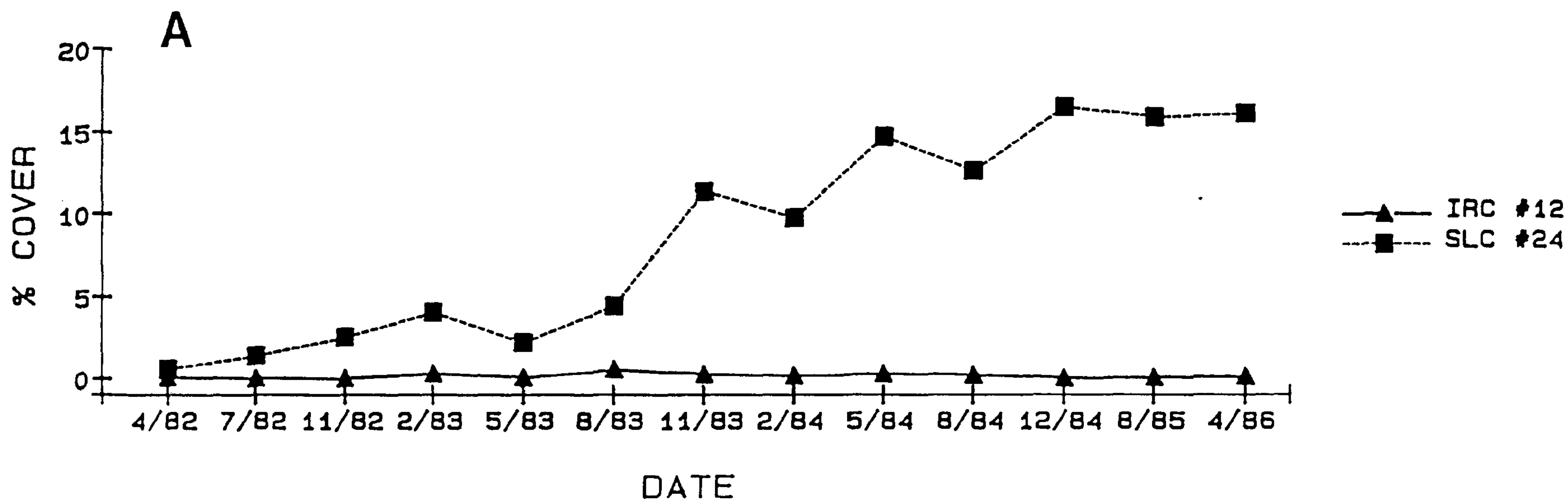

MEAN B. maritima COVER
A
% COVER
10
8
6
4
2
0
4/82 7/82 11/82 2/83 5/83 8/83 11/83 2/84 5/84 8/84 12/84 9/85 4/86
DATE
IRC #12
SLC #24
MEAN B. maritima FREQUENCY
B
FREQUENCY
0.4
0.3
0.2
0.1
0.0
4/82 7/82 11/82 2/83 5/83 8/83 11/83 2/84 5/84 8/84 12/84 9/85 4/86
DATE
IRC #12
SLC #24


MEAN R. mangle COVER
A
% COVER
6
4
2
0
4/82 7/82 11/82 2/83 5/83 8/83 11/83 2/84 5/84 8/84 12/84 8/85 4/86
DATE
IRC #12
SLC #24

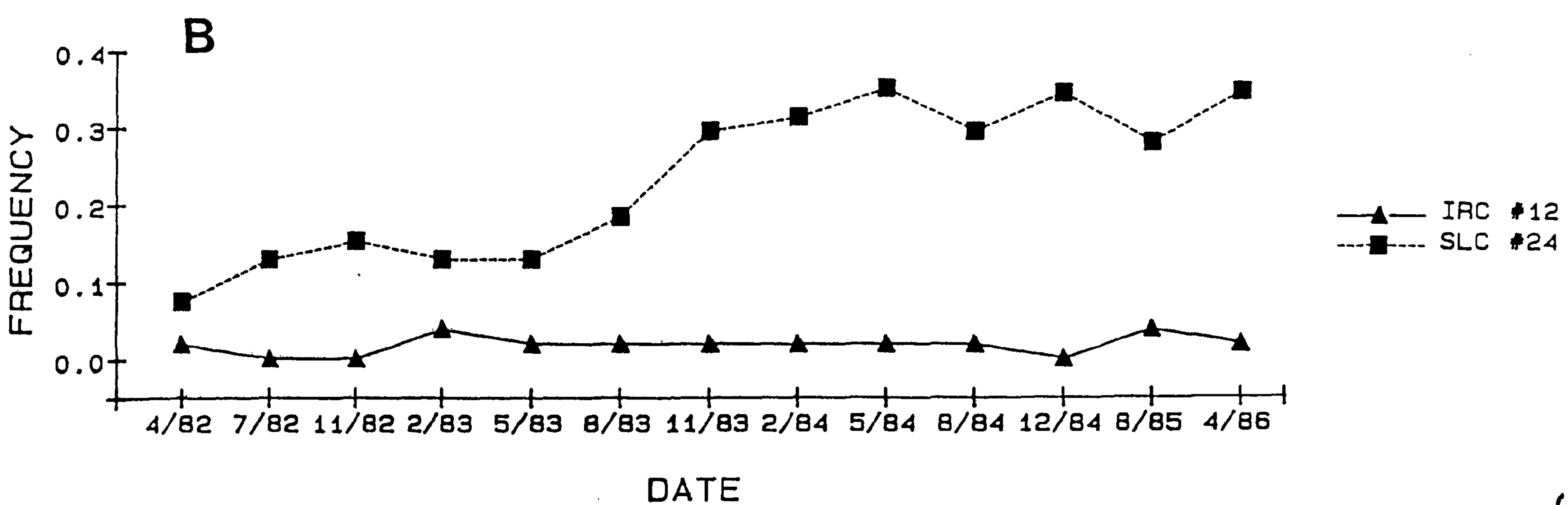

MEAN R.mangle FREQUENCY
B
FREQUENCY
0.10
0.08
0.06
0.04
0.02
0.00
4/82 7/82 11/82 2/83 5/83 8/83 11/83 2/84 5/84 8/84 12/84 8/85 4/86
DATE
IRC #12
SLC #24

8

MEAN A. germinans COVER

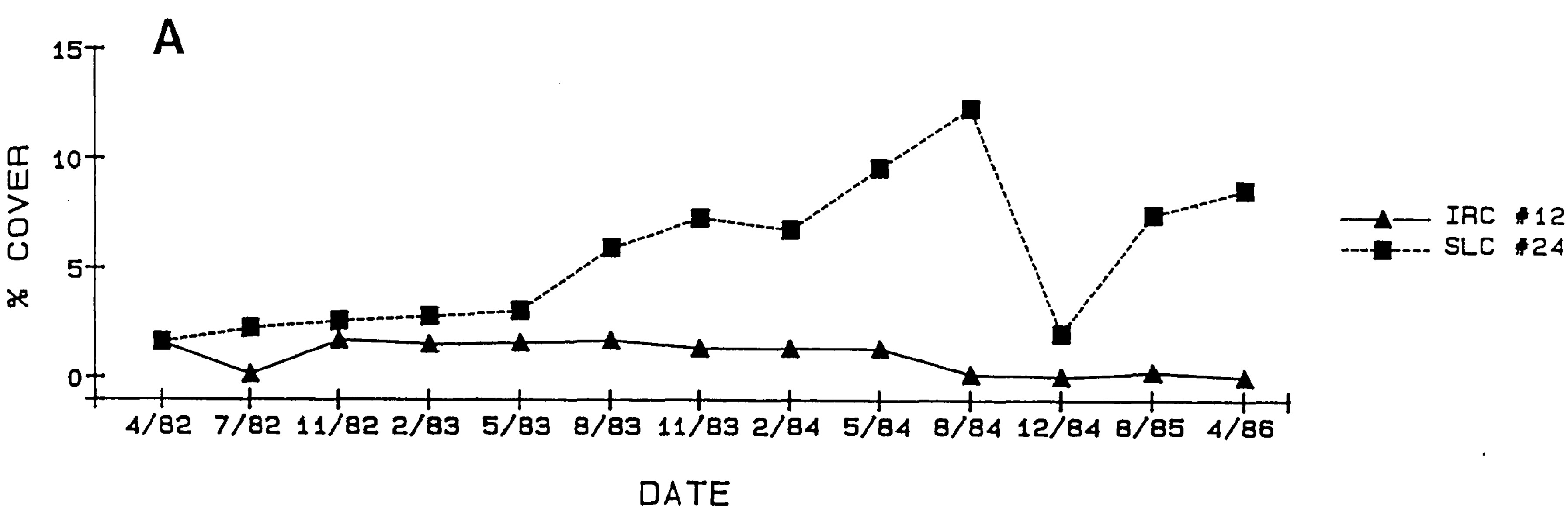


MEAN A. germinans FREQUENCY

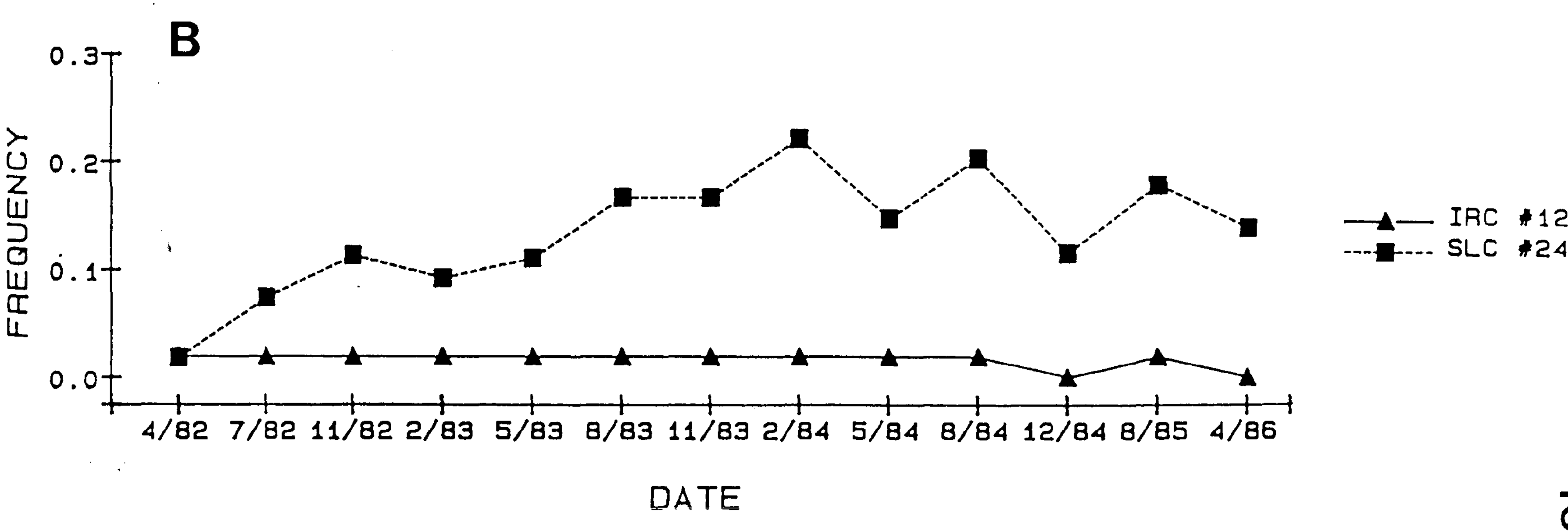


9

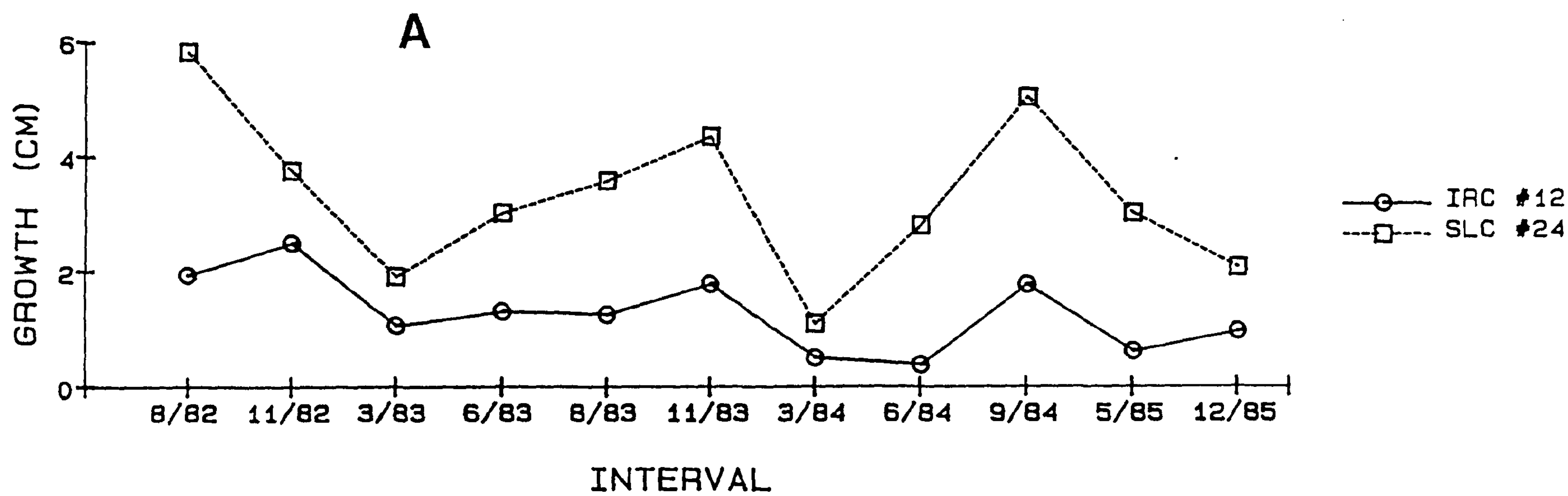
MEAN L. racemosa COVER



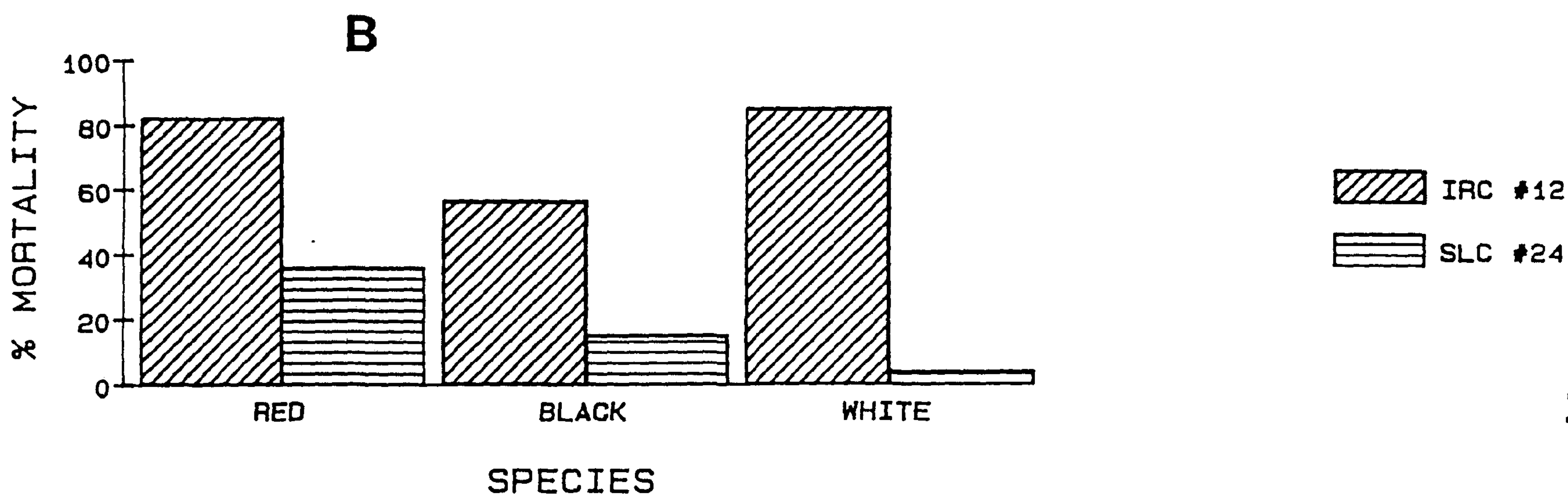
MEAN L. racemosa FREQUENCY



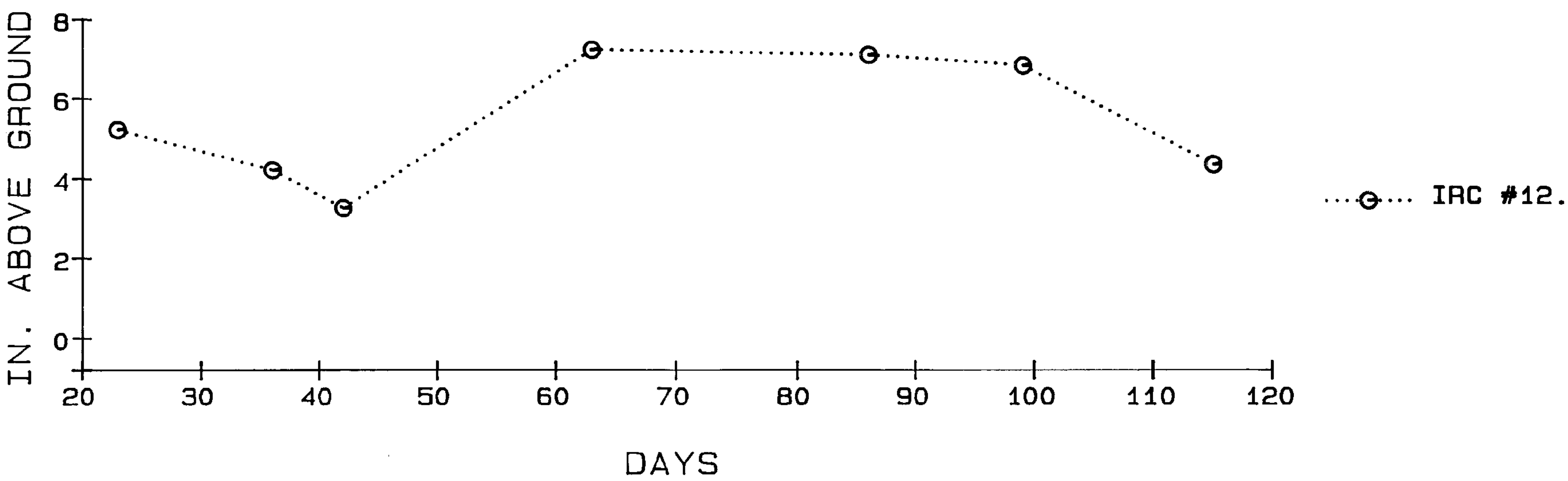
MEAN MANGROVE GROWTH PER MONTH



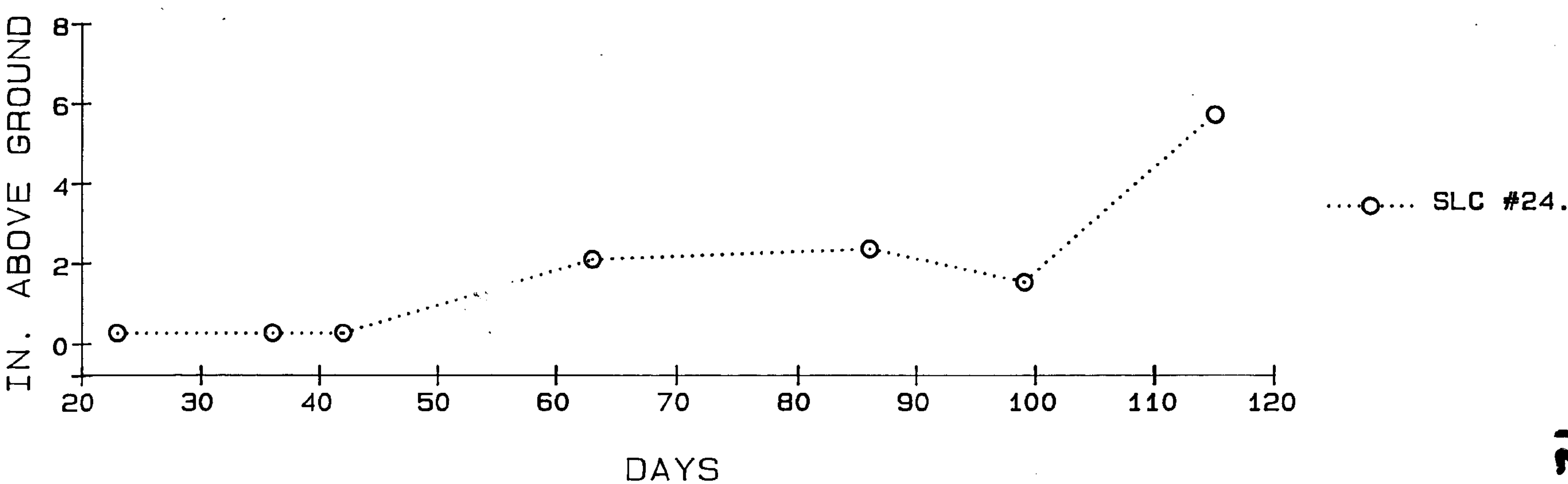
MANGROVE MORTALITY
1982 - 1985



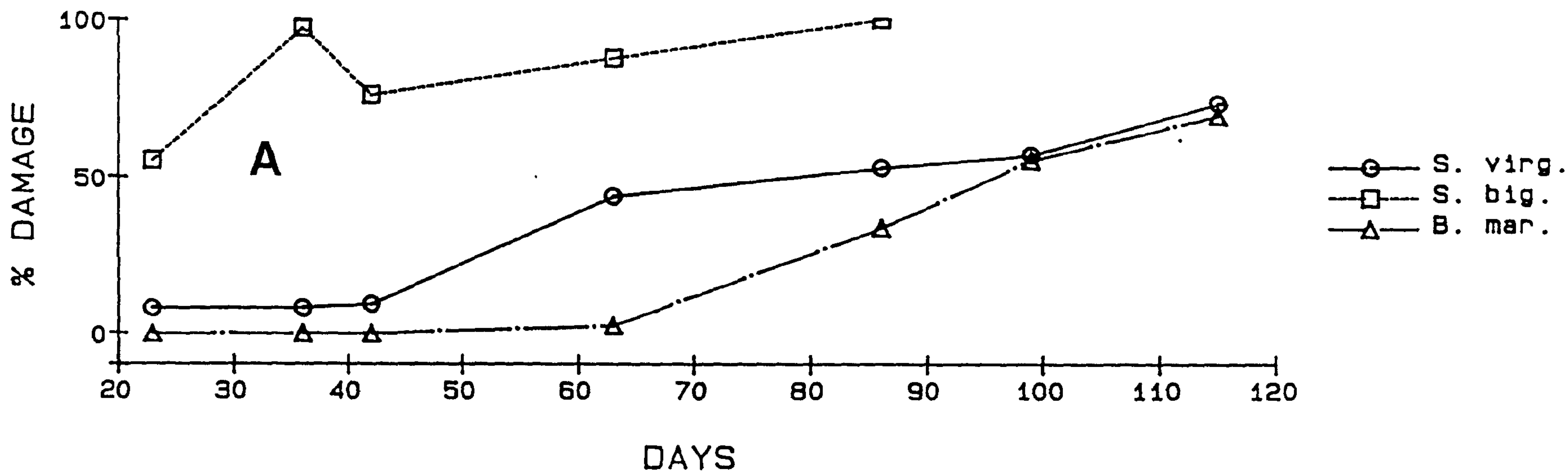
MEAN WATER LEVEL



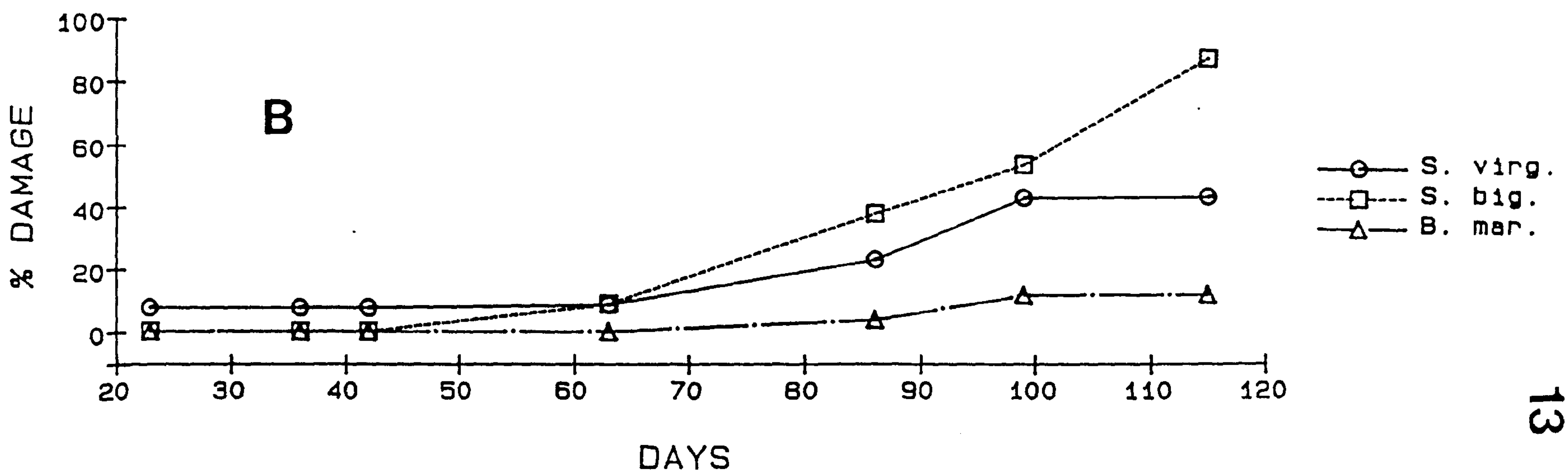
MEAN WATER LEVEL

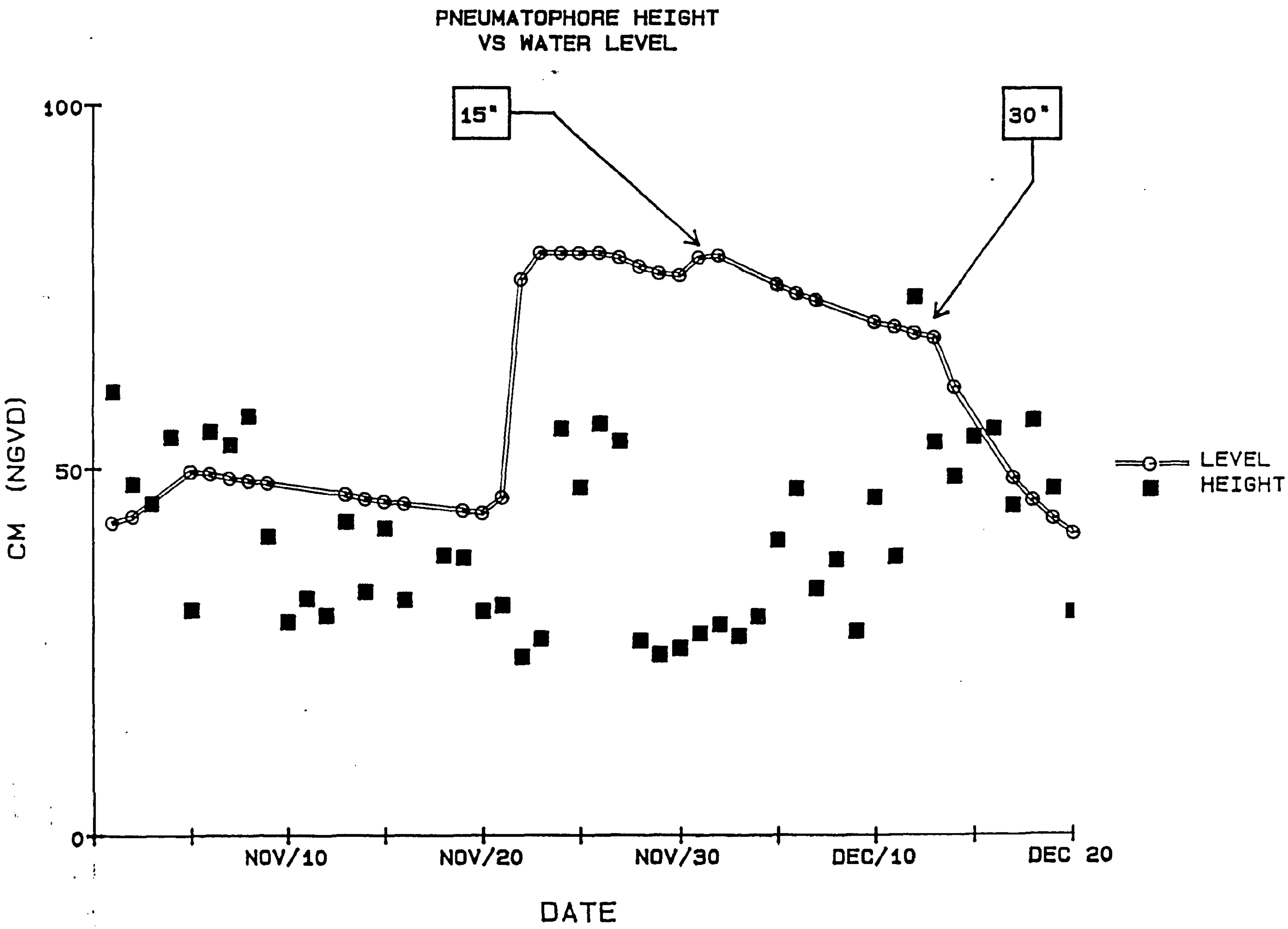


VEGETATION DAMAGE - IRC #12



VEGETATION DAMAGE - SLC #24




PNEUMATOPHORE HEIGHT
VS WATER LEVEL
15"
30"
100
50
0
CM (NGVD)
NOV/10
NOV/20
NOV/30
DEC/10
DEC 20
DATE
LEVEL
HEIGHT

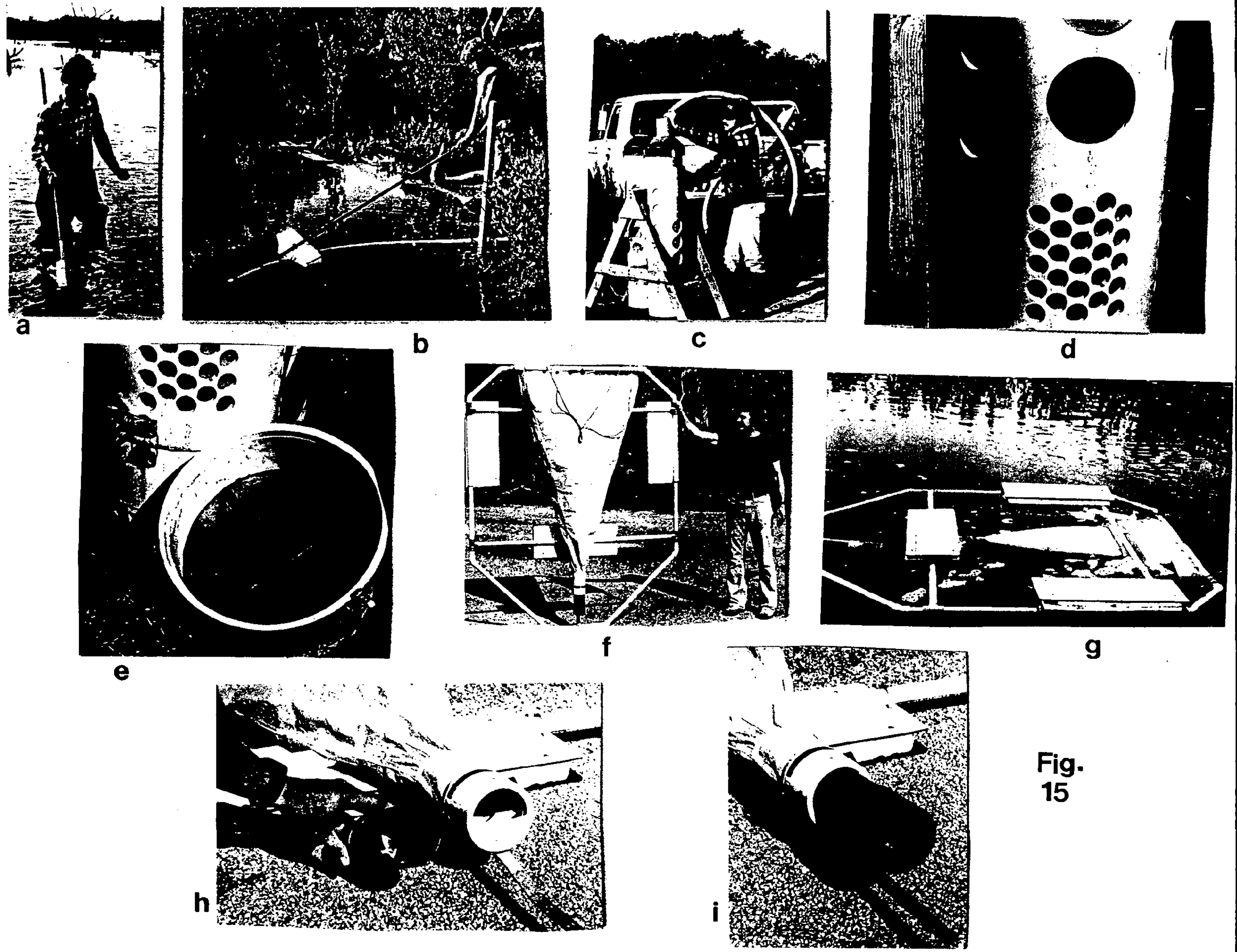
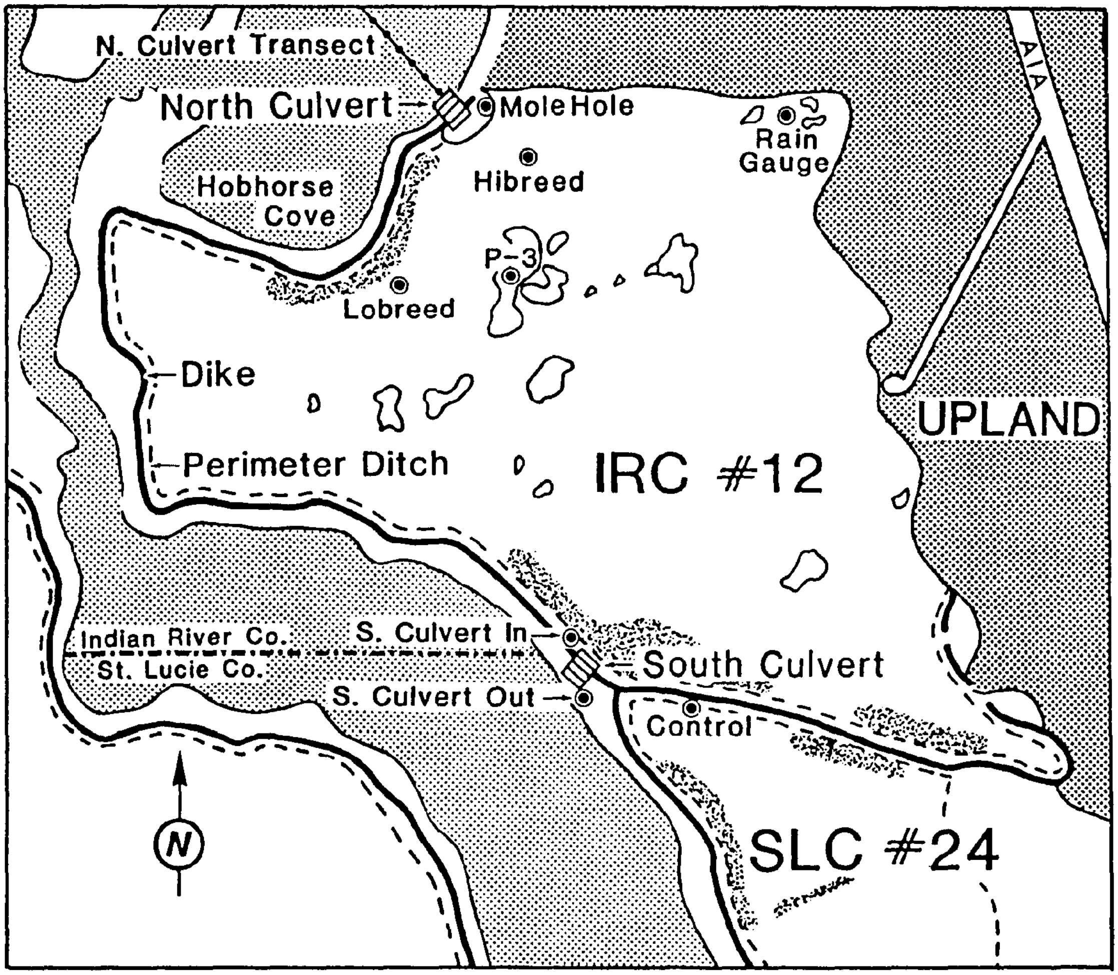
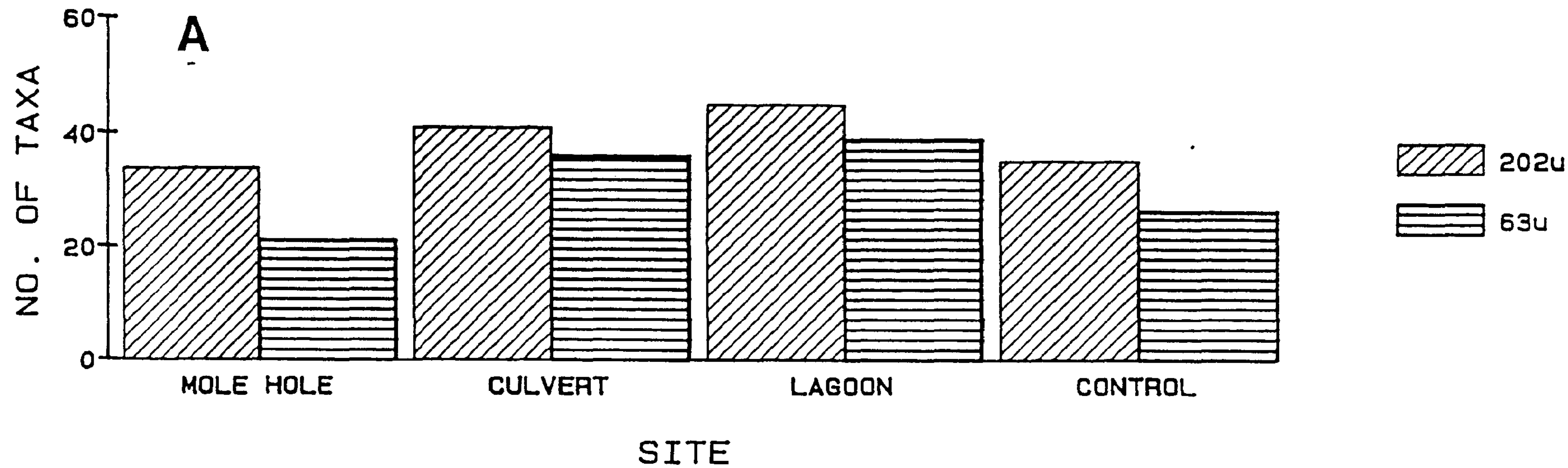


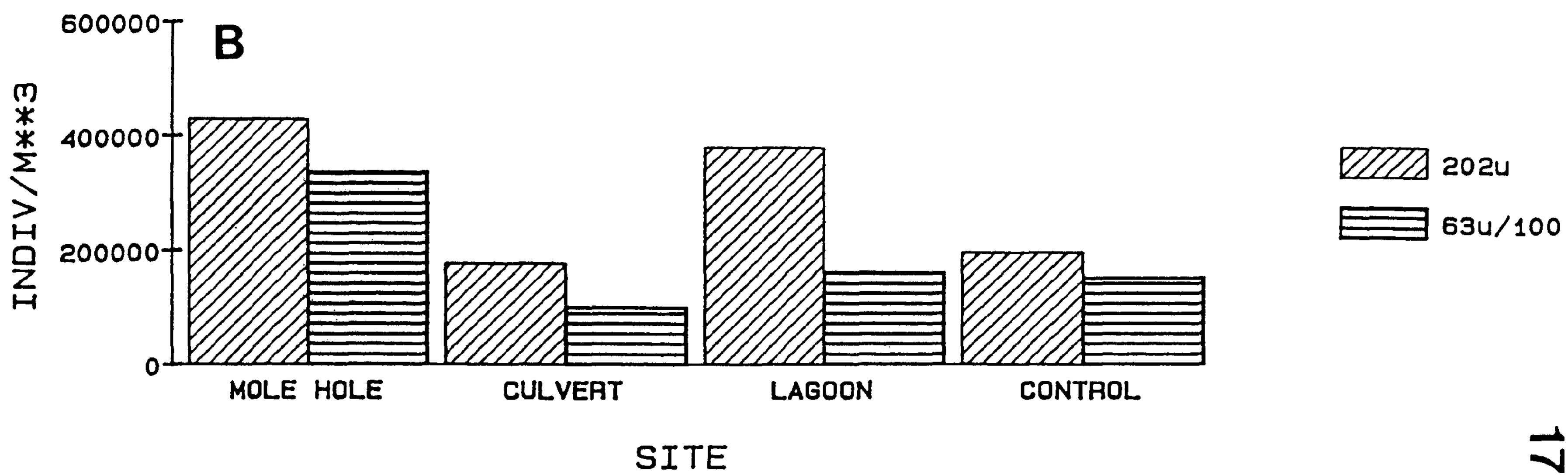
Fig. 15

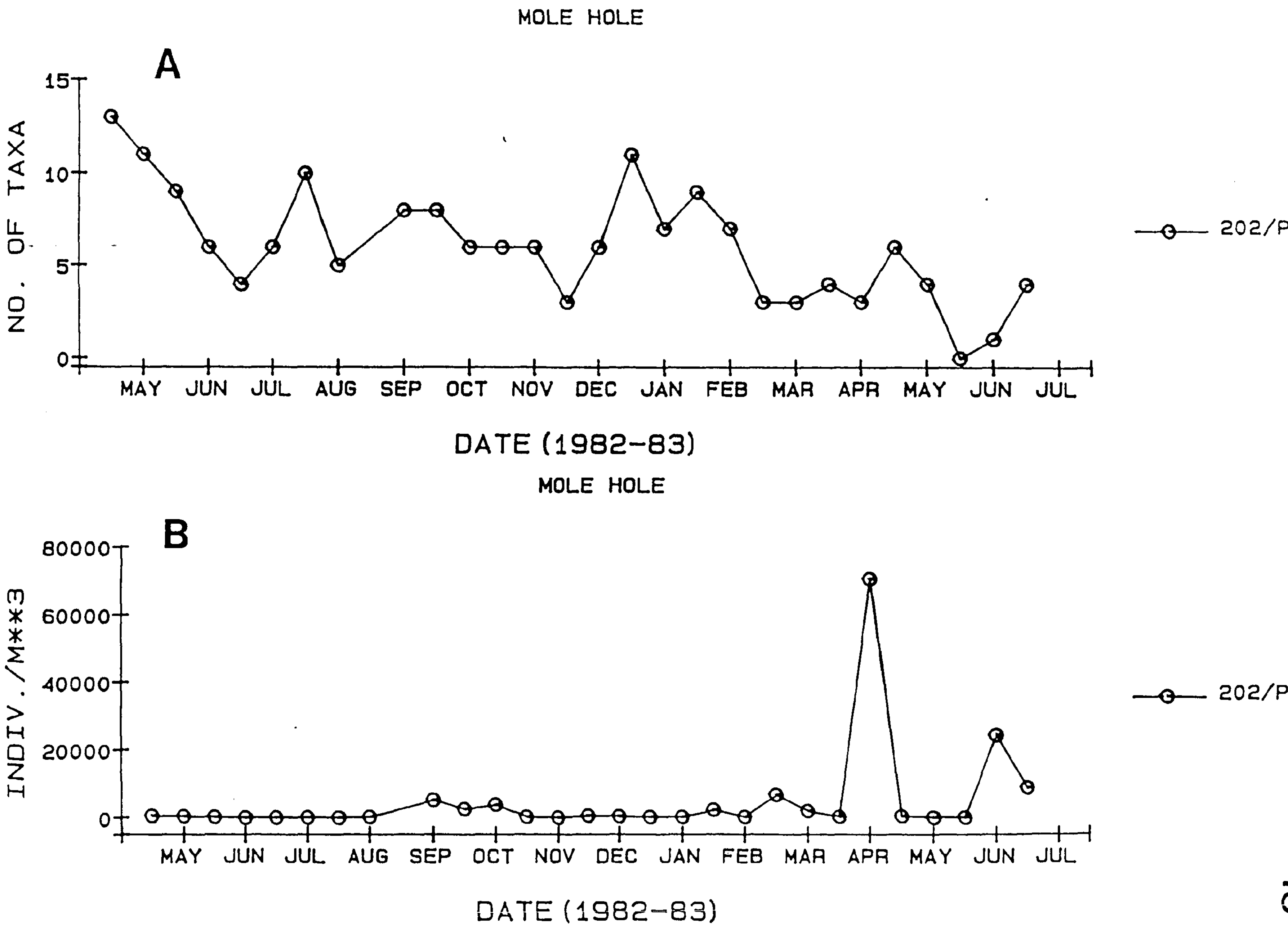

N. Culvert Transect
North Culvert
Mole Hole
Rain
Gauge
A1A
Hobhorse
Cove
Hibreed
P-3
Lobreed
Dike
UPLAND
Perimeter Ditch
IRC #12
Indian River Co.
St. Lucie Co.
S. Culvert In
South Culvert
S. Culvert Out
Control
N
SLC #24

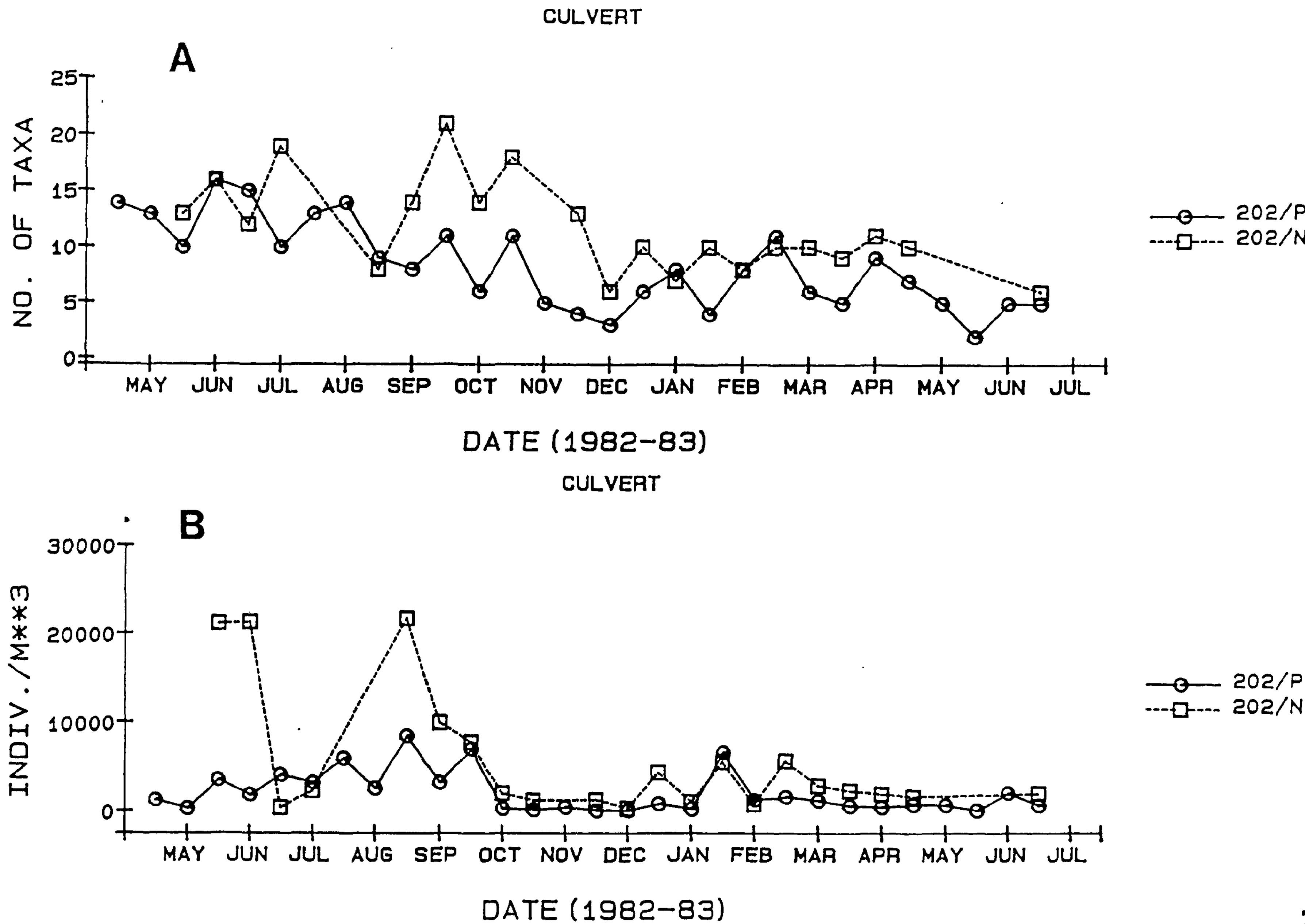
COMBINED TAXA

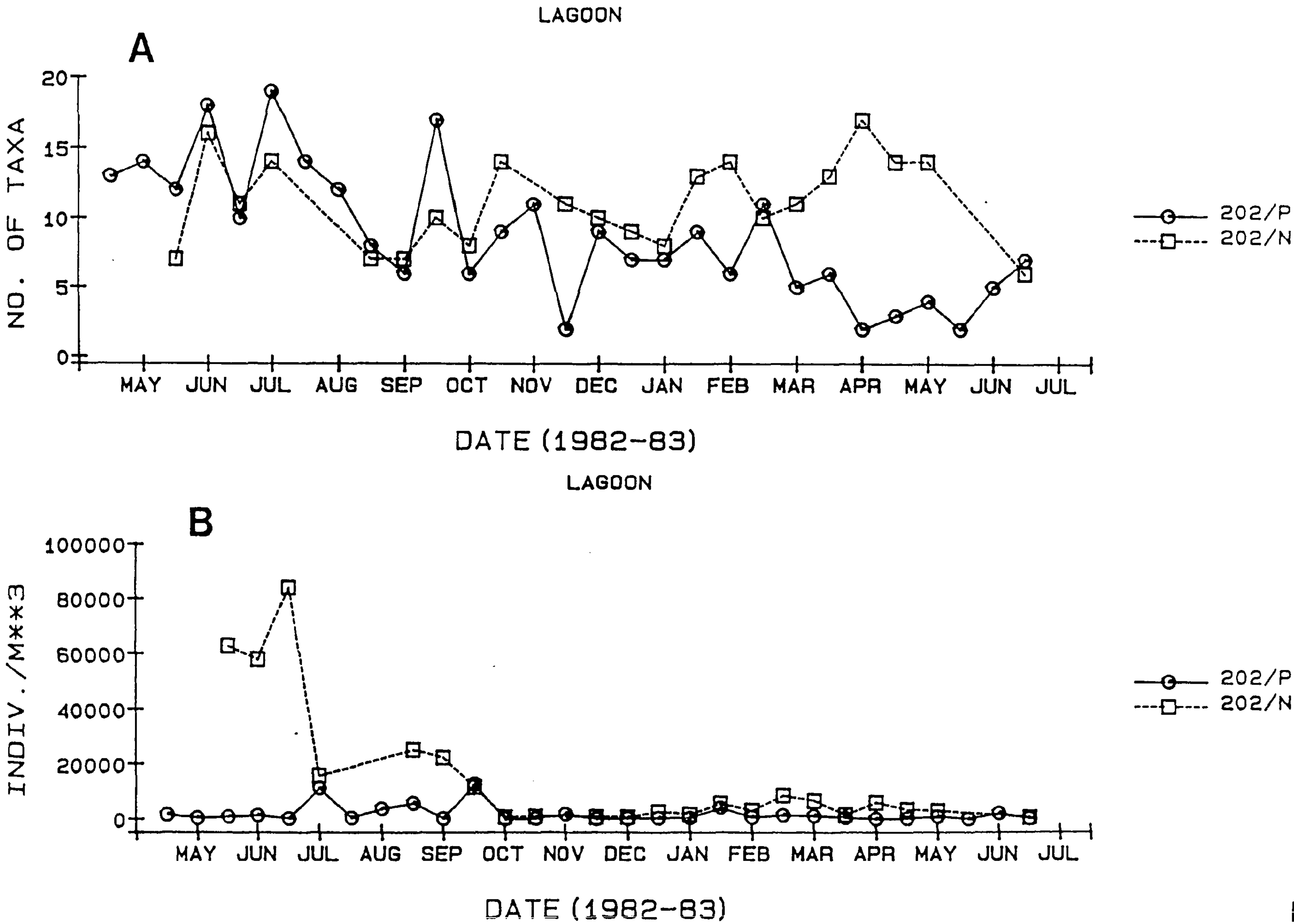


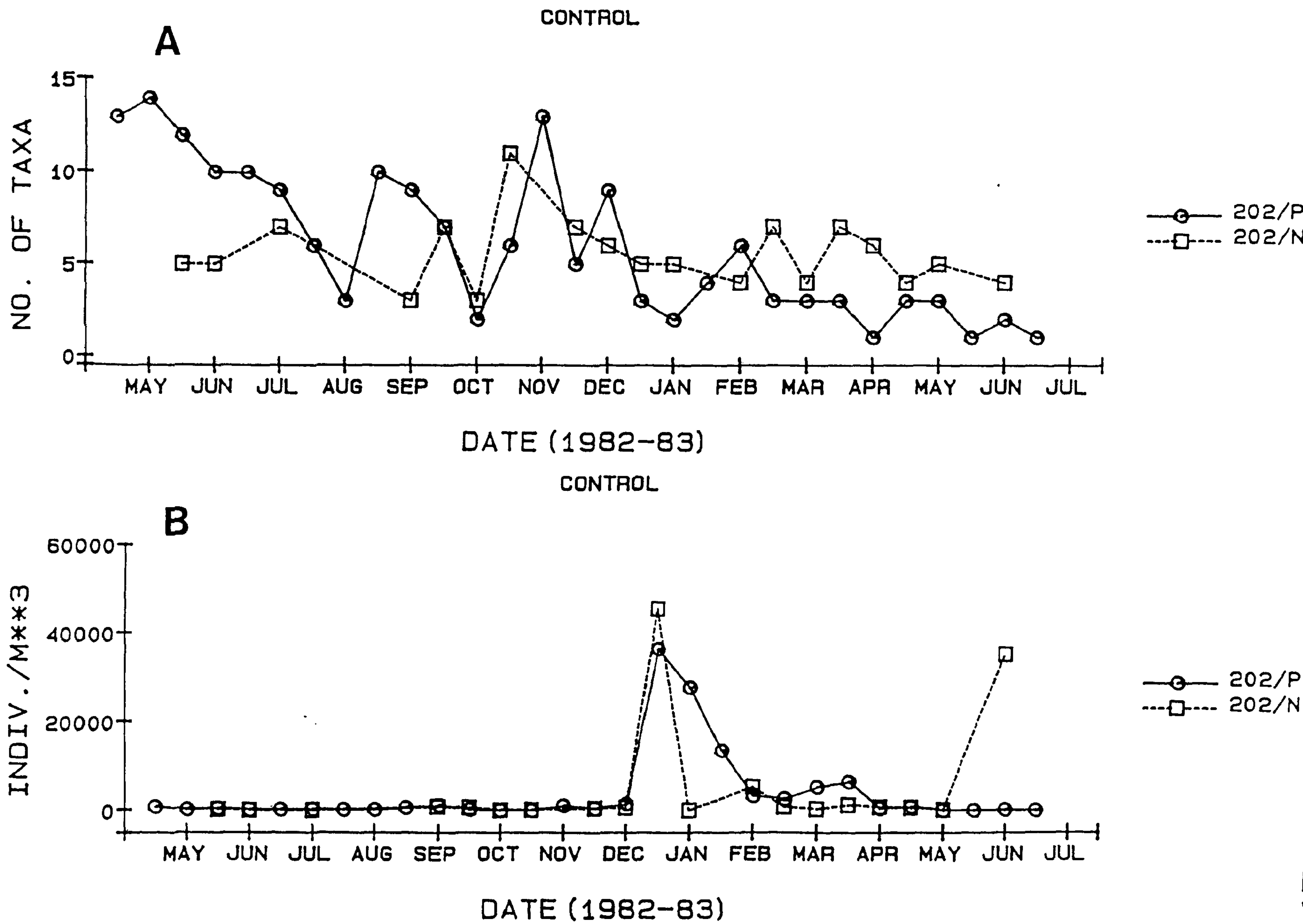
TOTAL DENSITIES

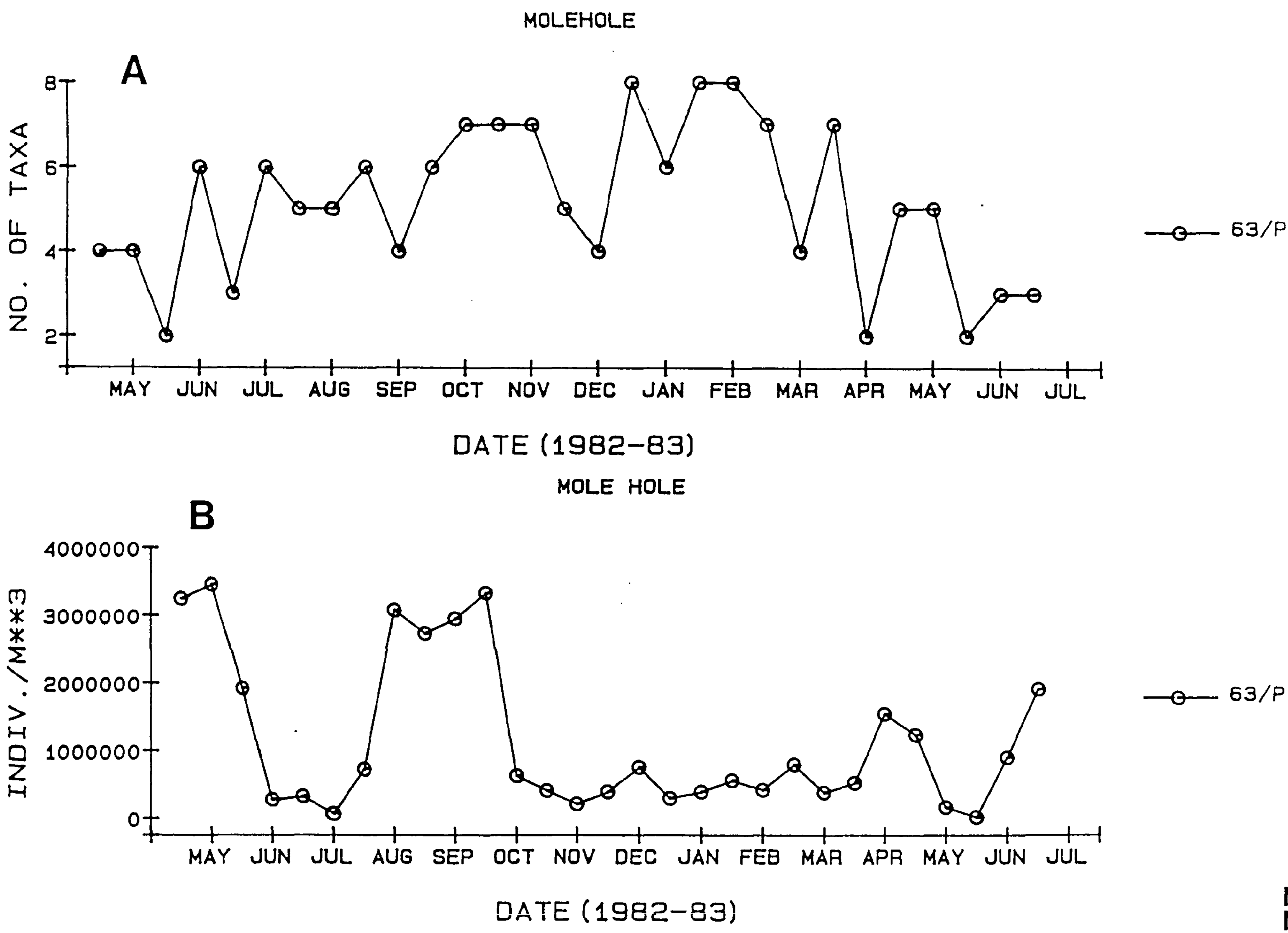



MOLE HOLE
A
NO. OF TAXA
15
10
5
0
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL
DATE (1982-83)
202/P
MOLE HOLE
B
INDIV./M**3
80000
60000
40000
20000
0
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL
DATE (1982-83)
202/P


CULVERT
A
NO. OF TAXA
25
20
15
10
5
0
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL
DATE (1982-83)
202/P
202/N
CULVERT
B
INDIV./M**3
30000
20000
10000
0
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL
DATE (1982-83)
202/P
202/N


LAGOON
A
NO. OF TAXA
20
15
10
5
0
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL
DATE (1982-83)
202/P
202/N
LAGOON
B
INDIV./M**3
100000
80000
60000
40000
20000
0
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL
DATE (1982-83)
202/P
202/N


CONTROL
A
NO. OF TAXA
15
10
5
0
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
DATE (1982-83)
202/P
202/N
CONTROL
B
INDIV./M**3
60000
40000
20000
0
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
DATE (1982-83)
202/P
202/N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A
NO. OF TAXA
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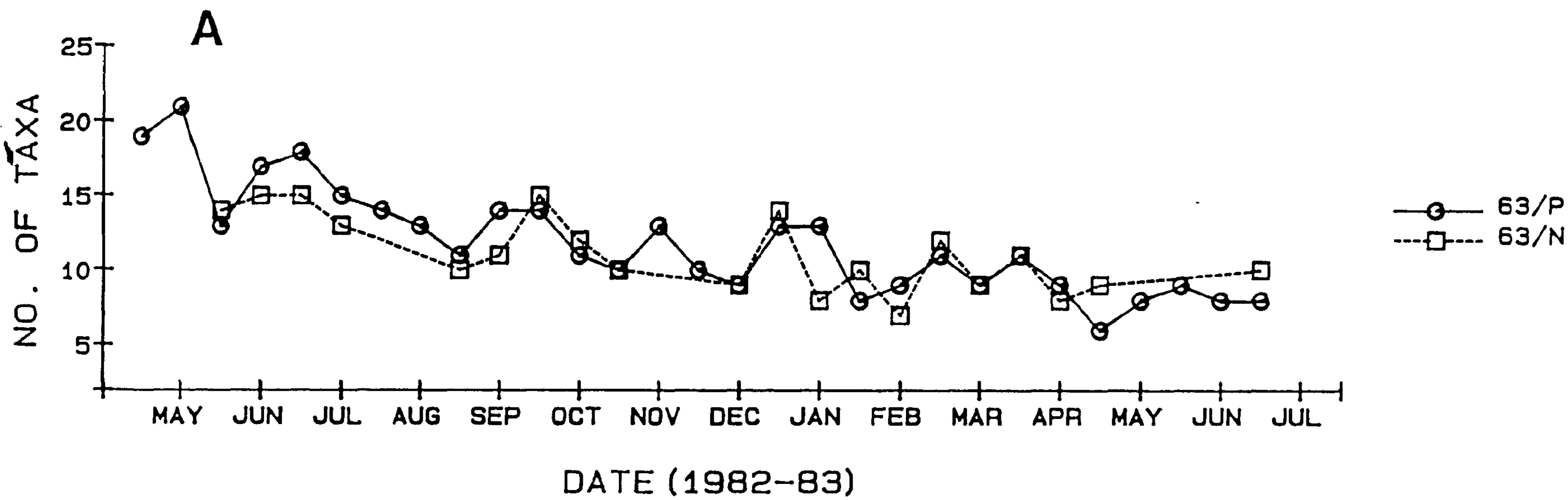
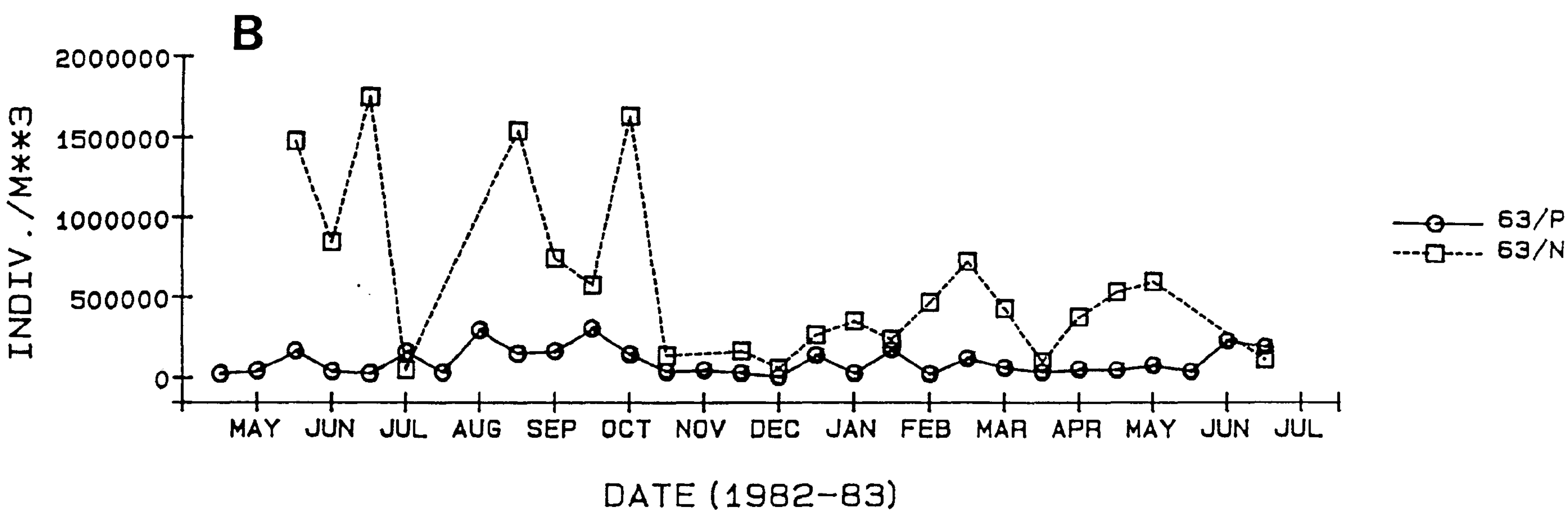
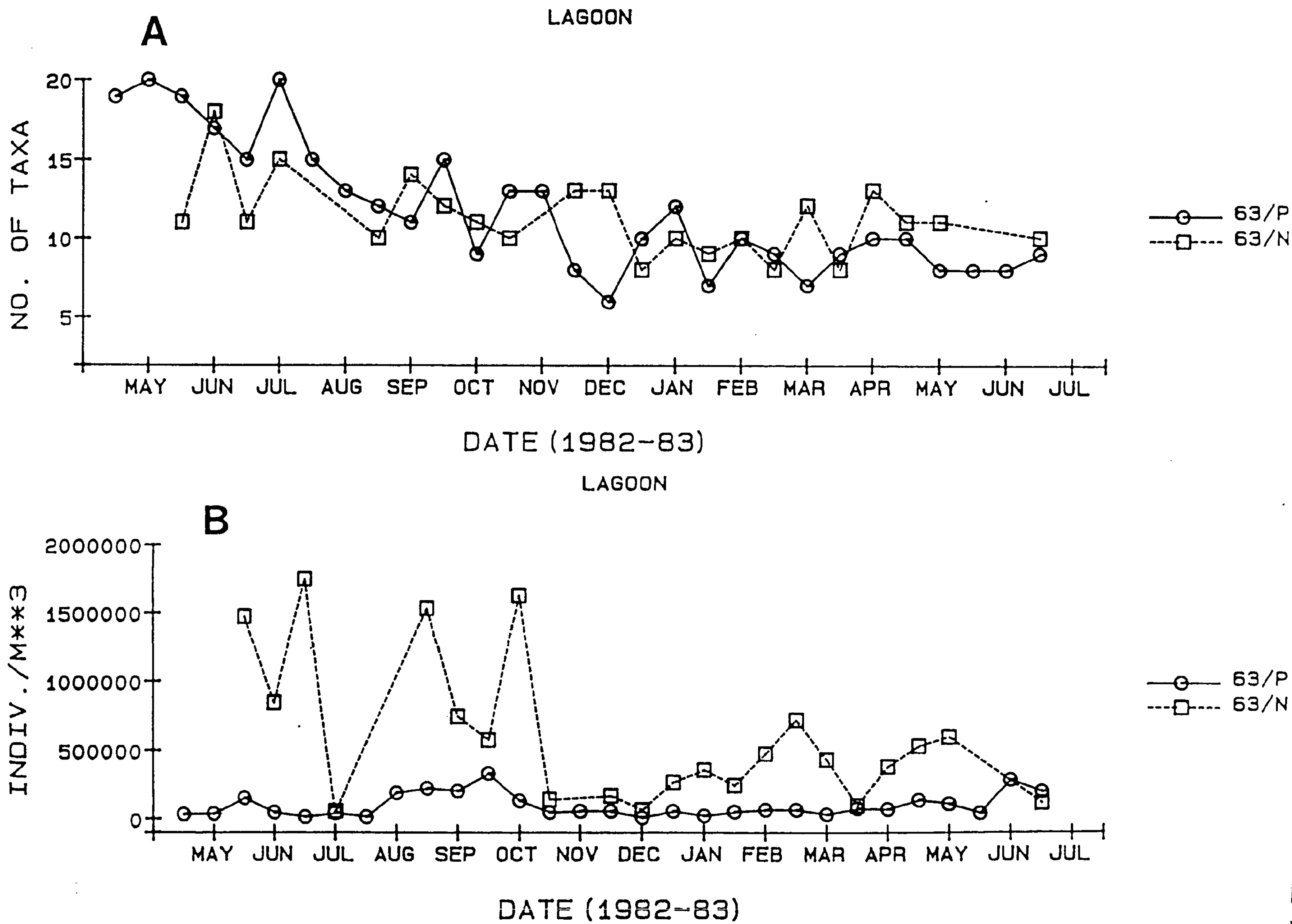
4
2
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL
DATE (1982-83)
63/P
MOLE HOLE
B
INDIV./M**3
4000000
3000000
2000000
1000000
0
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL
DATE (1982-83)
63/P

CULVERT



CULVERT




LAGOON
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15
10
5
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL
DATE (1982-83)
63/P
63/N
LAGOON
B
INDIV./M**3
2000000
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1000000
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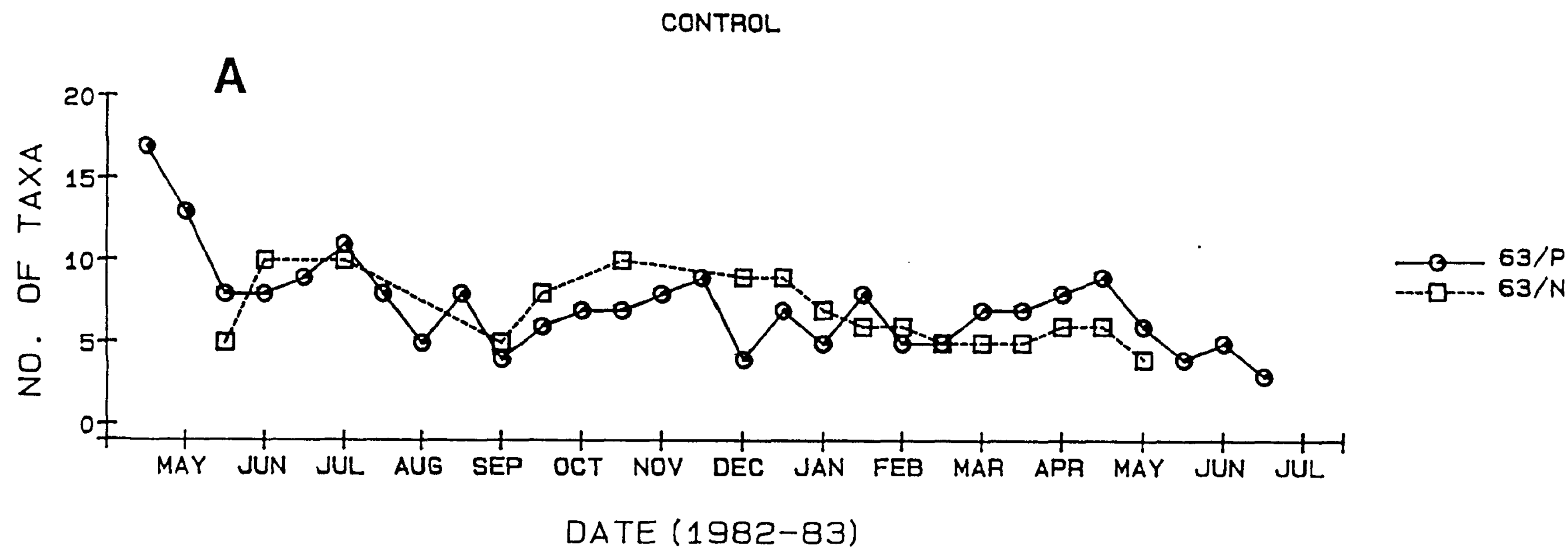
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL
DATE (1982-83)
63/P
63/N


CONTROL
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NO. OF TAXA
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10
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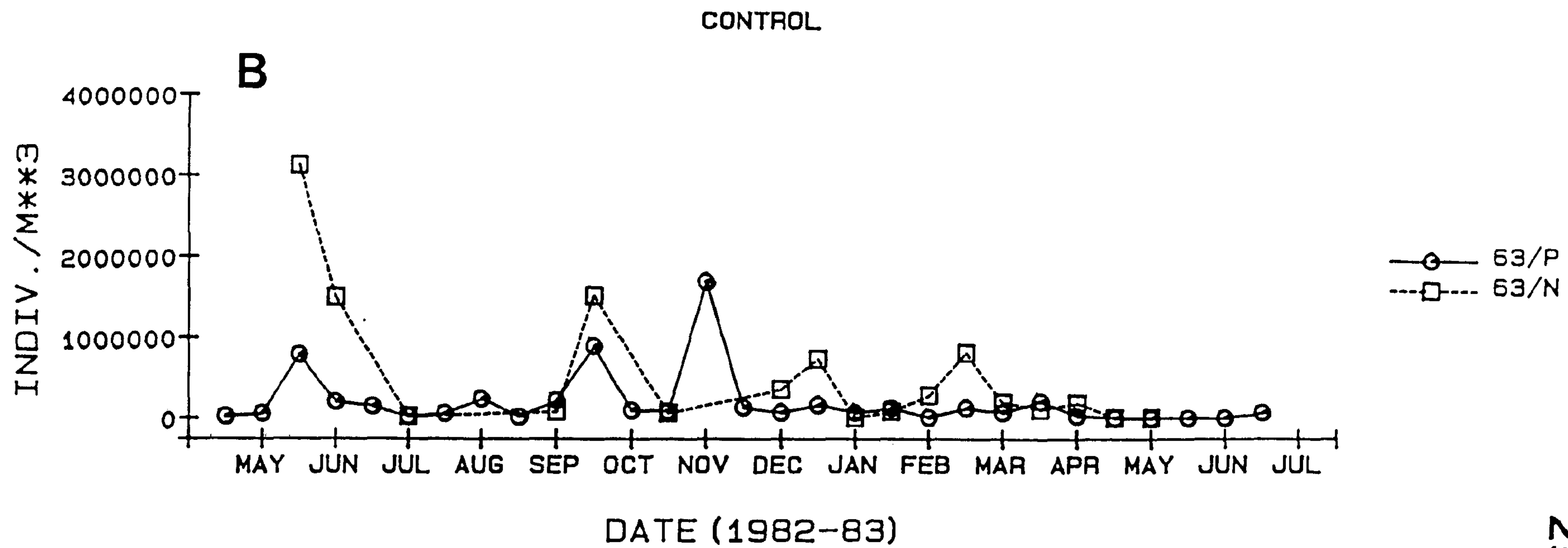
DATE (1982-83)
63/P
63/N


CONTROL
B
INDIV./M**3
4000000
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2000000
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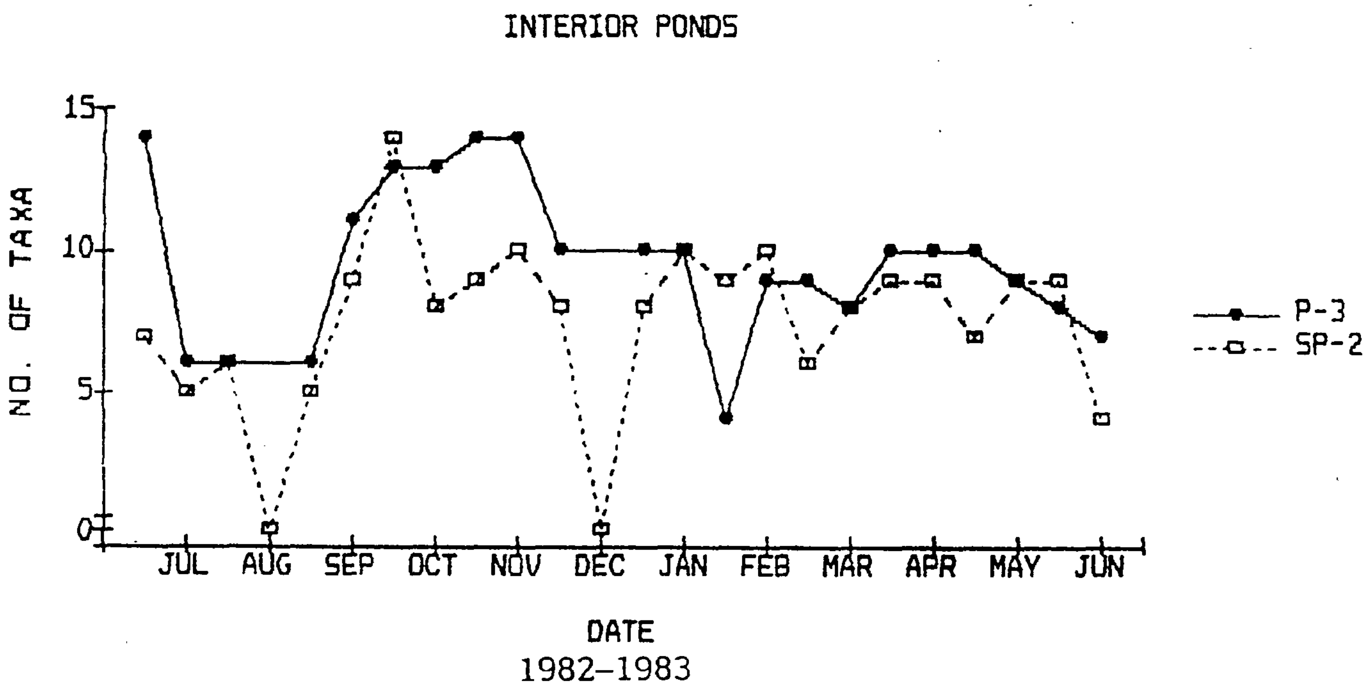
0
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL
DATE (1982-83)
63/P
63/N


INTERIOR PONDS
NO. OF TAXA
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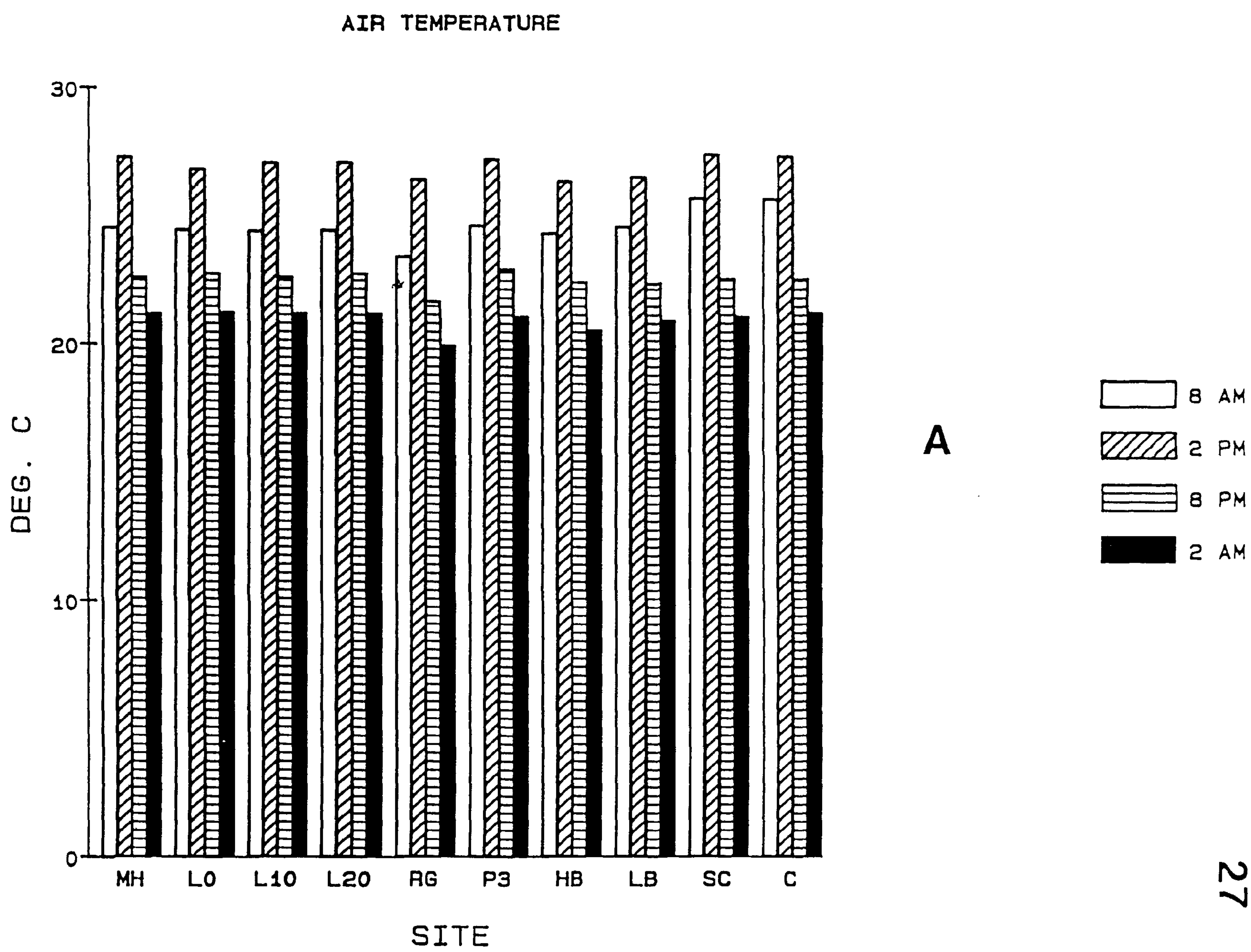
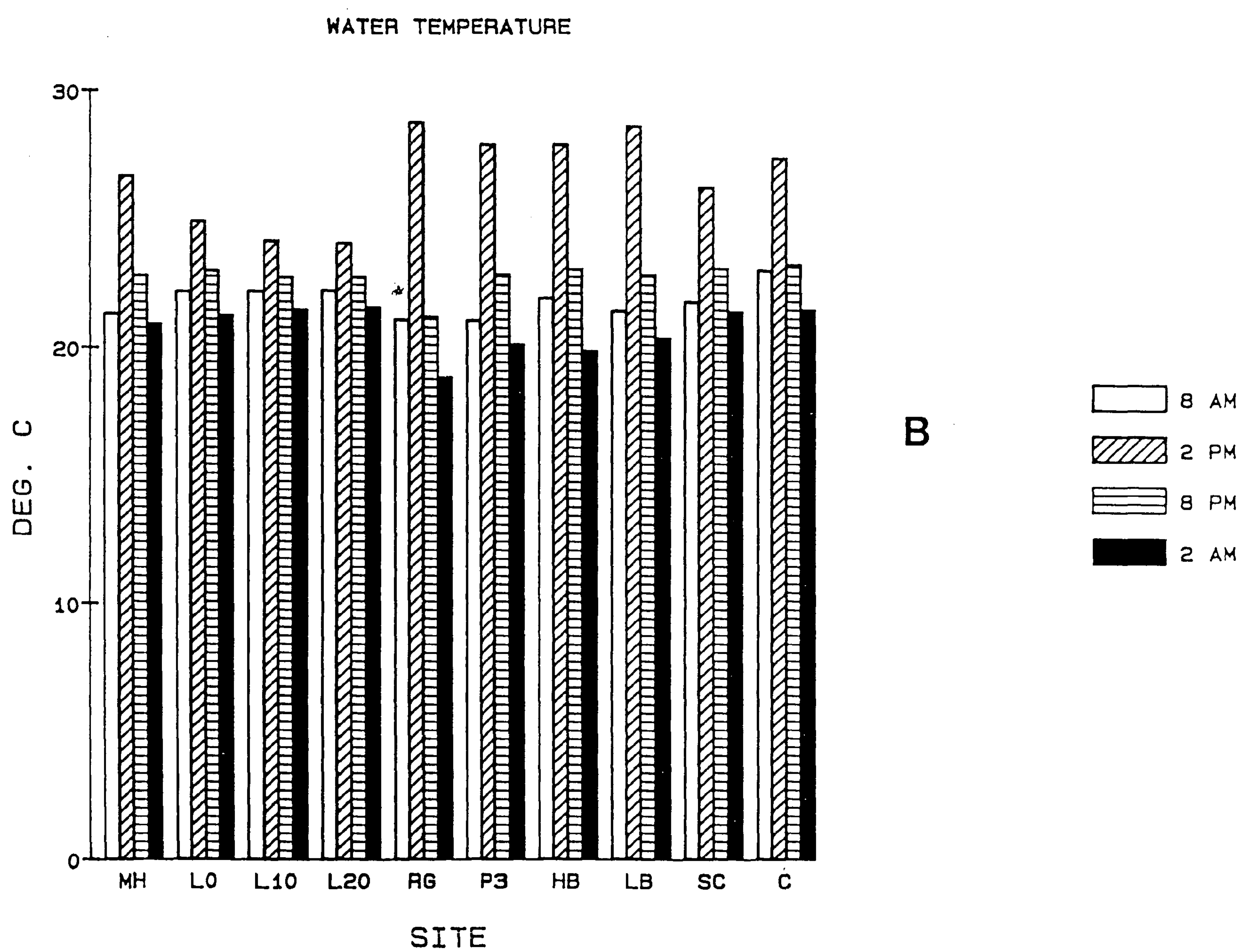
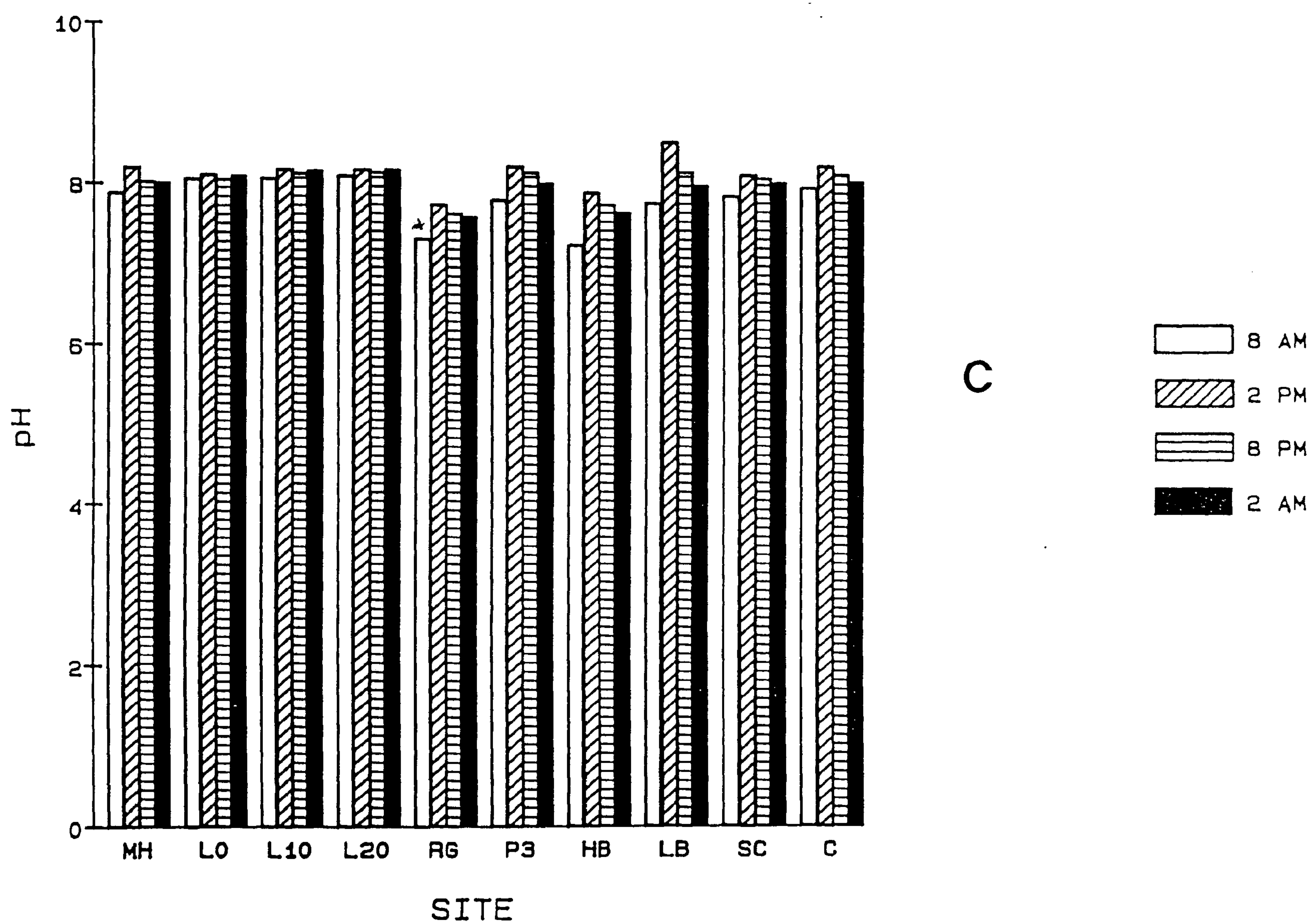
10
5
0
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
P-3
SP-2
DATE
1982–1983

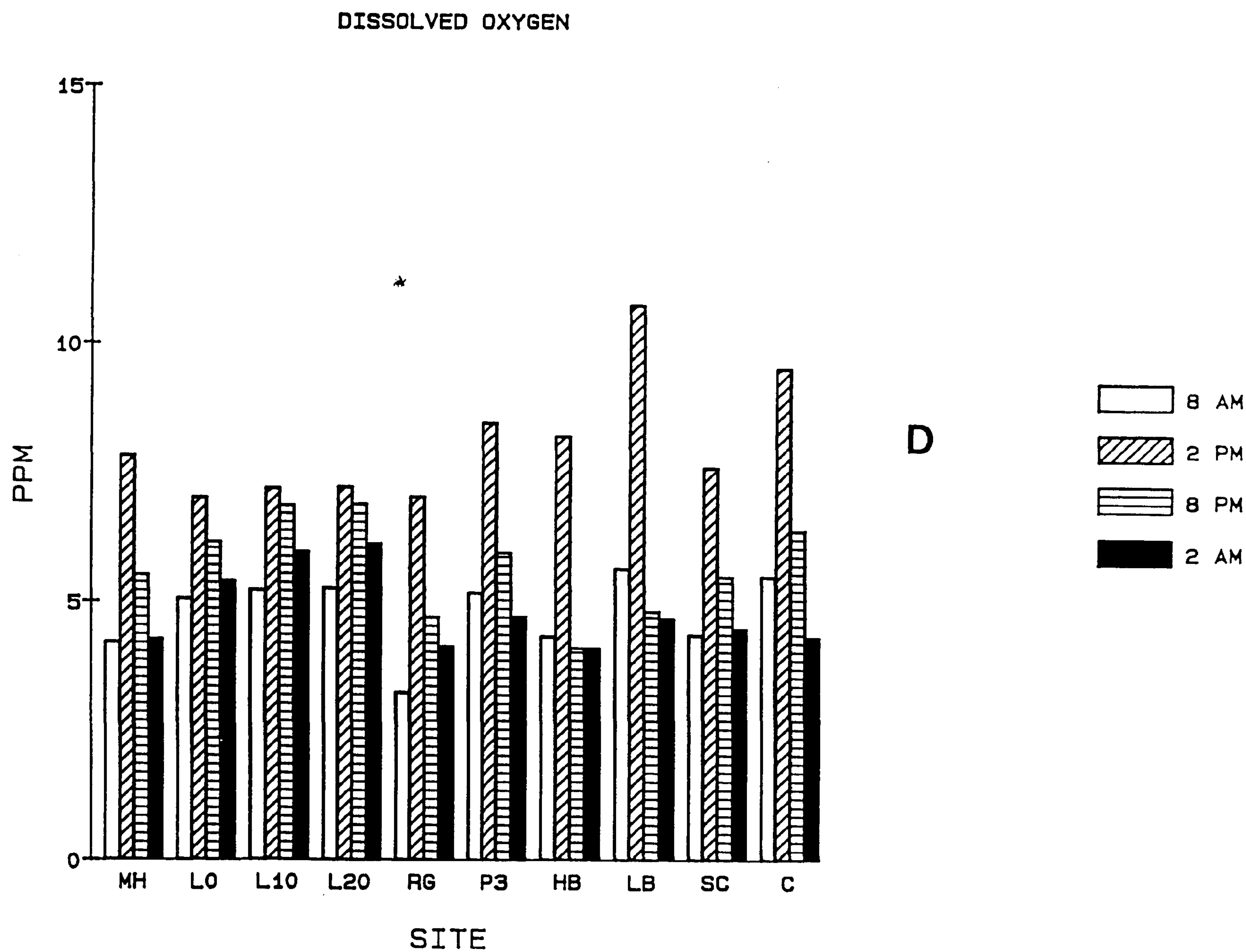

AIR TEMPERATURE
DEG. C
30
20
10
0
MH
L0
L10
L20
RG
P3
HB
LB
SC
C
SITE
A
8 AM
2 PM
8 PM
2 AM


WATER TEMPERATURE
30
20
10
0
DEG. C
MH
L0
L10
L20
RG
P3
HB
LB
SC
C
SITE
B
8 AM
2 PM
8 PM
2 AM

pH

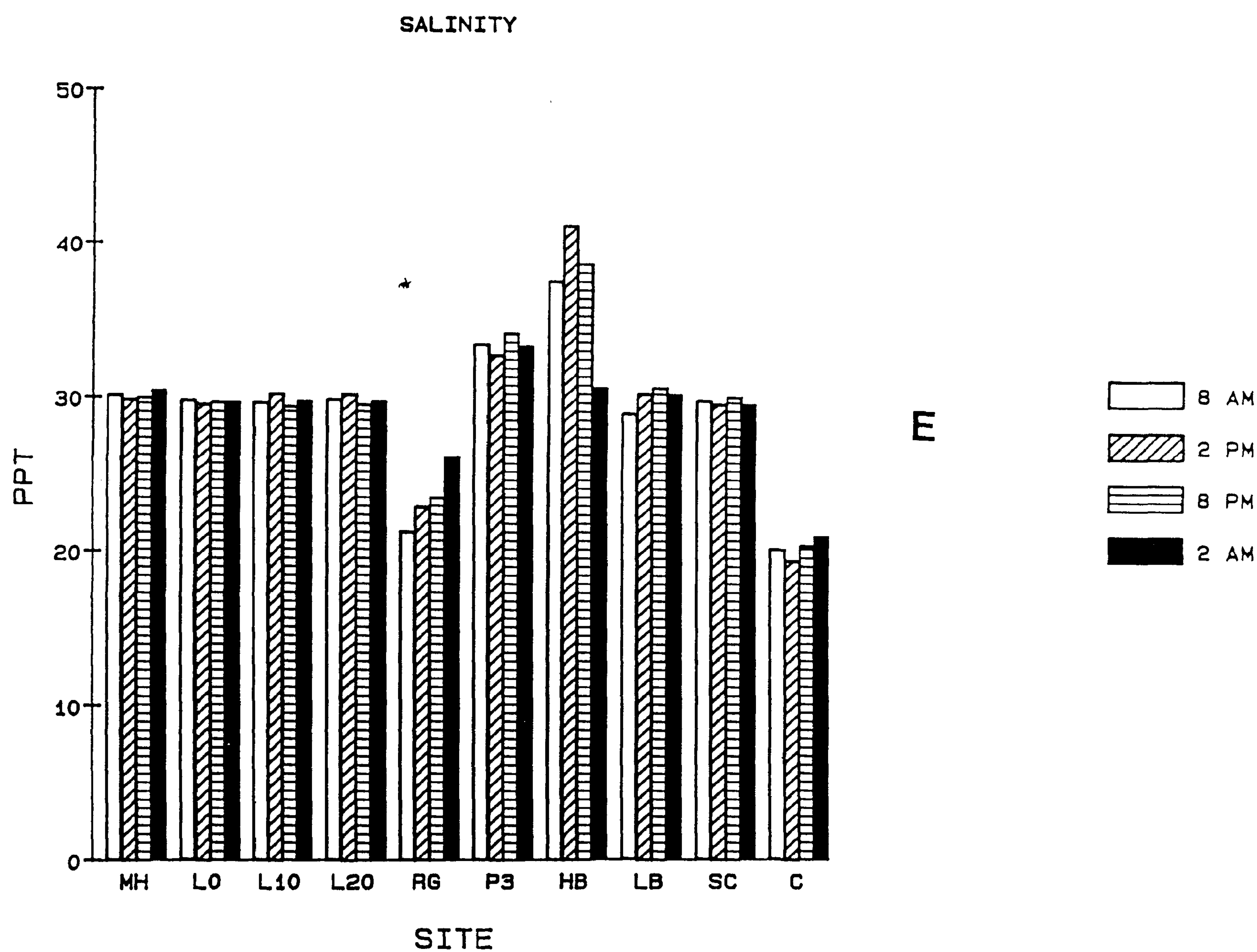


C



DISSOLVED OXYGEN
15
10
5
0
PPM
MH
L0
L10
L20
RG
P3
HB
LB
SC
C
SITE
8 AM
2 PM
8 PM
2 AM

D


SALINITY
PPT
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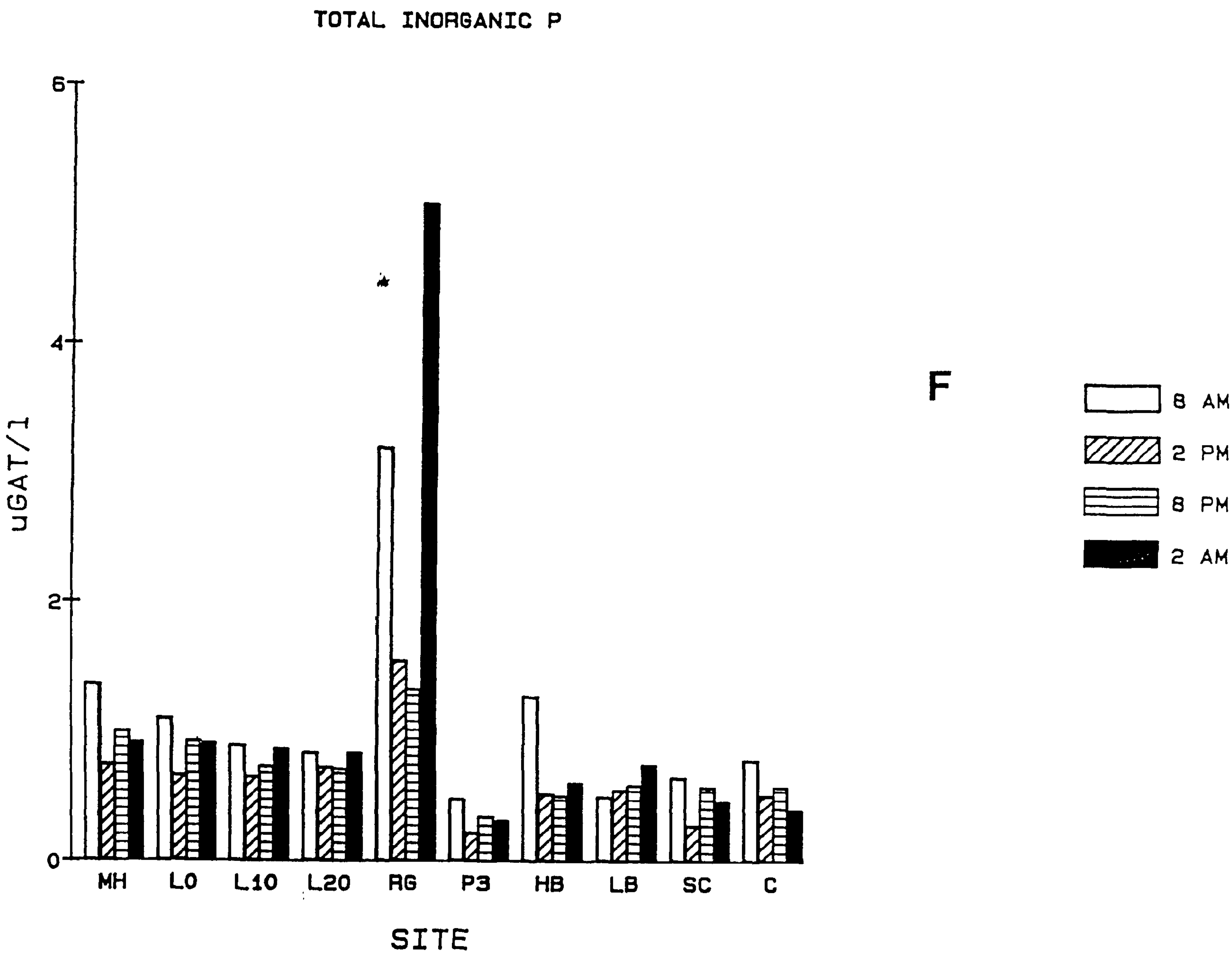
40
30
20
10
0
MH
L0
L10
L20
RG
P3
HB
LB
SC
C
SITE
8 AM
2 PM
8 PM
2 AM
E


TOTAL INORGANIC P
6
4
2
0
uGAT/1
MH
L0
L10
L20
RG
P3
HB
LB
SC
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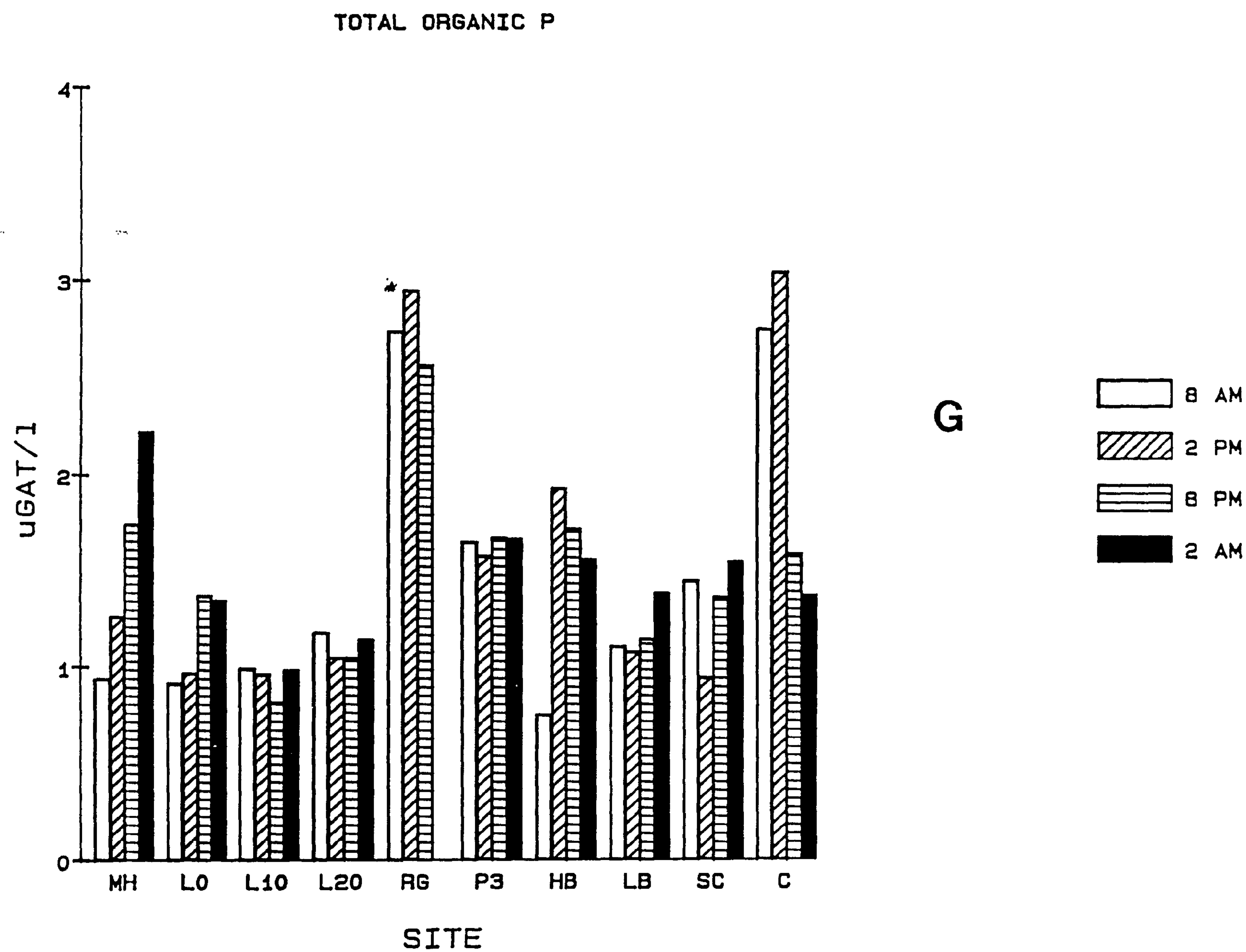
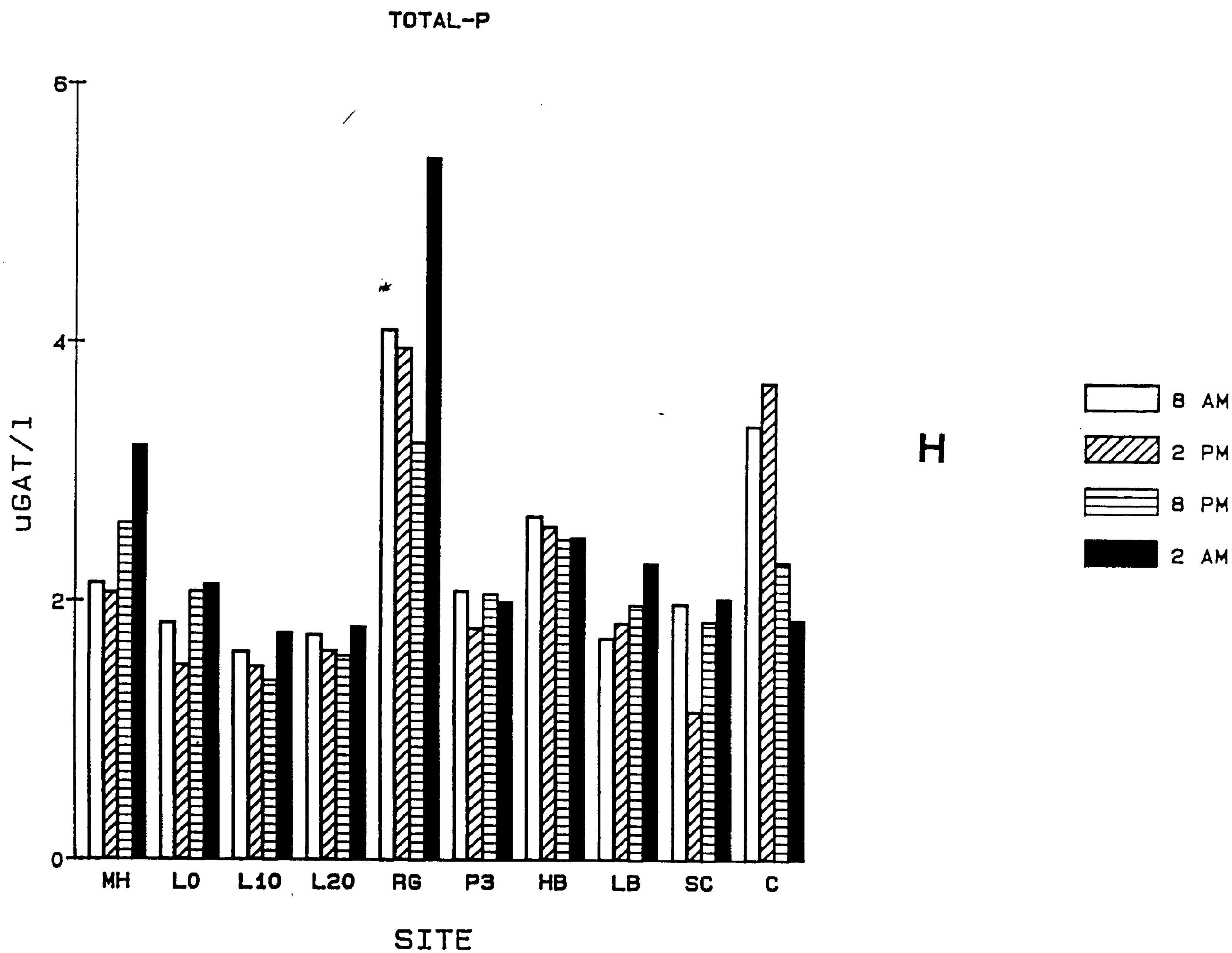
SITE
F
8 AM
2 PM
8 PM
2 AM



TOTAL ORGANIC P
uGAT/1
0
1
2
3
4
MH
L0
L10
L20
RG
P3
HB
LB
SC
C
SITE
8 AM
2 PM
8 PM
2 AM

G


TOTAL-P
uGAT/l
0
2
4
6
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L10
L20
RG
P3
HB
LB
SC
C
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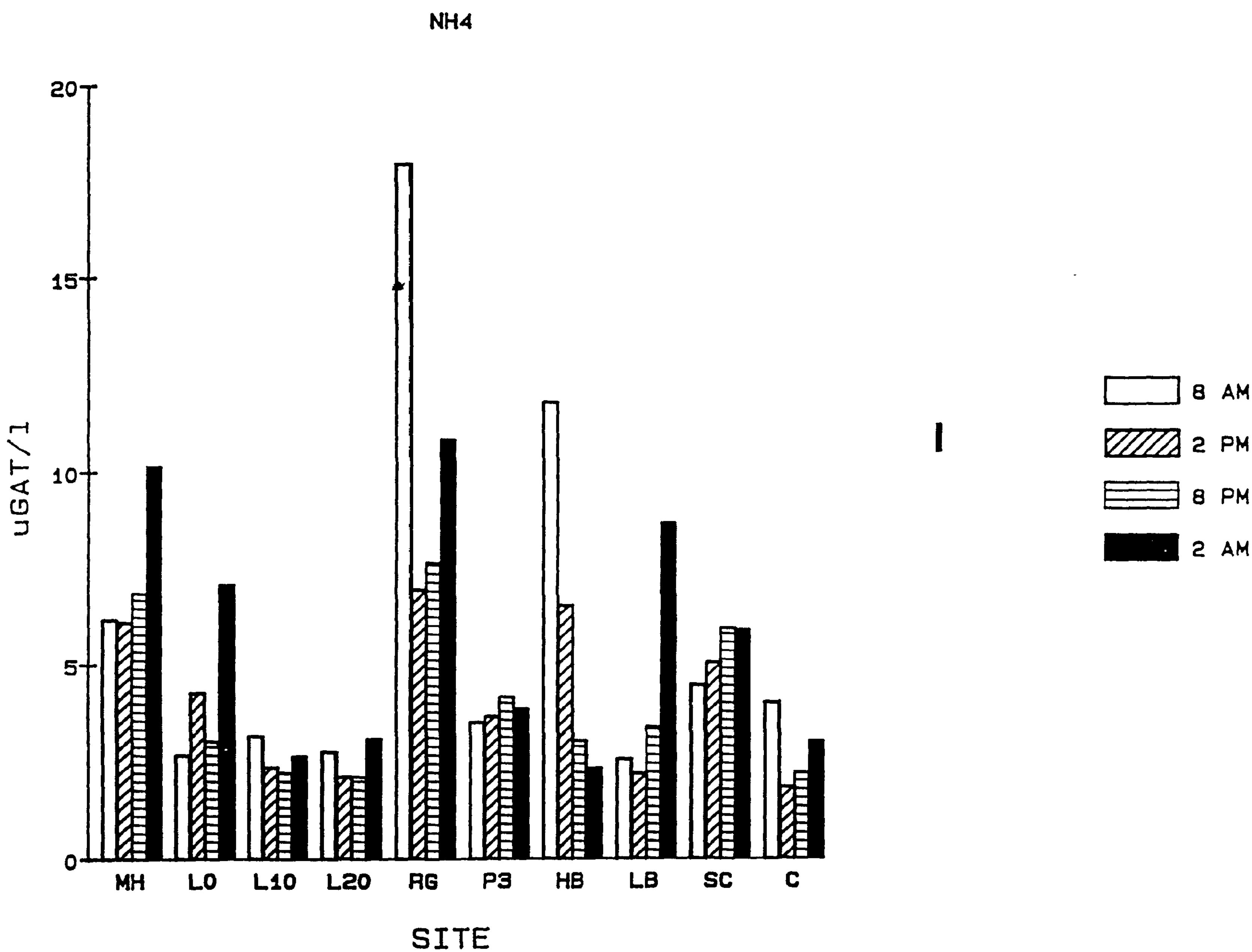
2 PM
8 PM
2 AM
H


NH4
20
15
10
5
0
uGAT/1
MH
L0
L10
L20
RG
P3
HB
LB
SC
C
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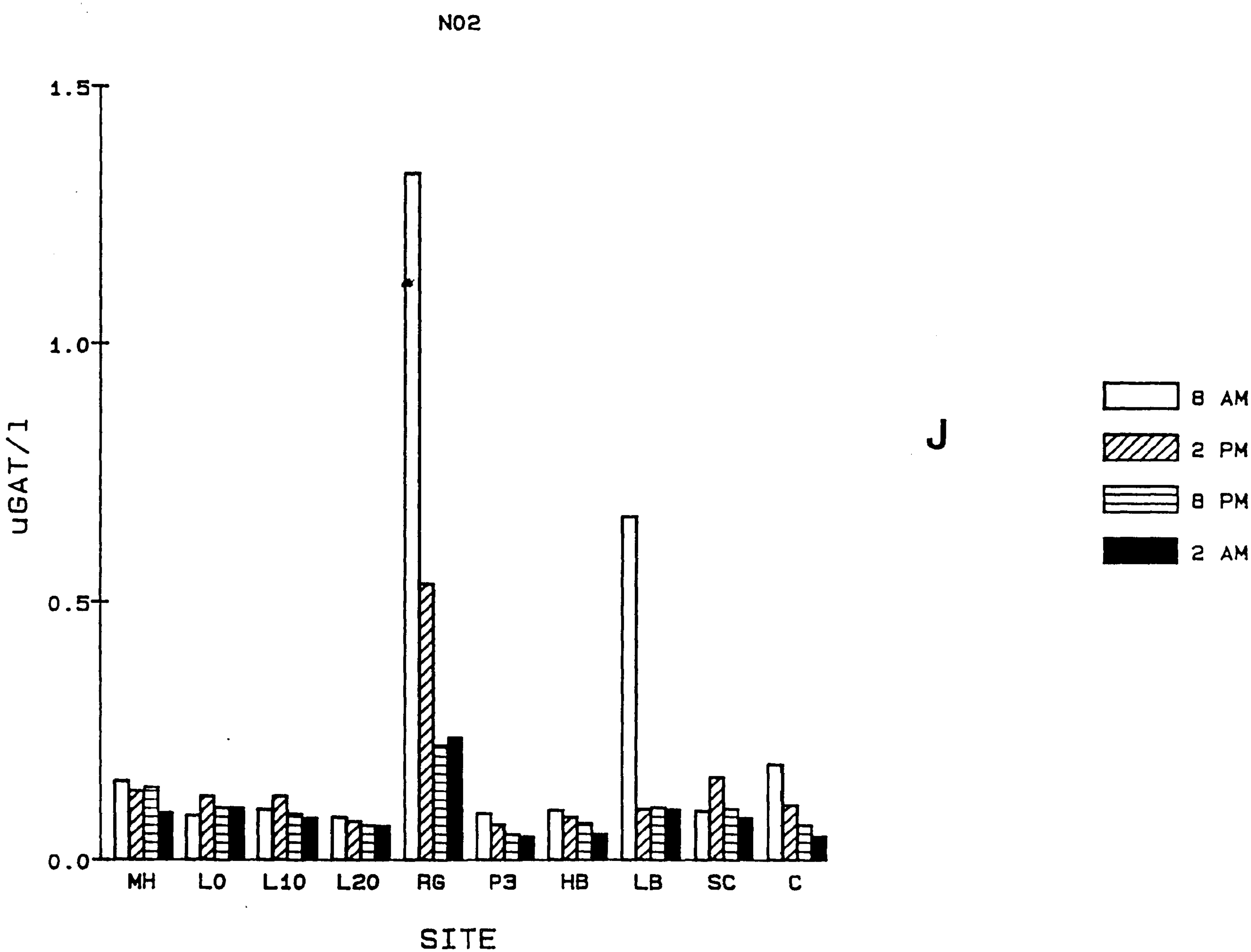
8 AM
2 PM
8 PM
2 AM



N02
1.5
1.0
0.5
0.0
uGAT/1
MH
L0
L10
L20
RG
P3
HB
LB
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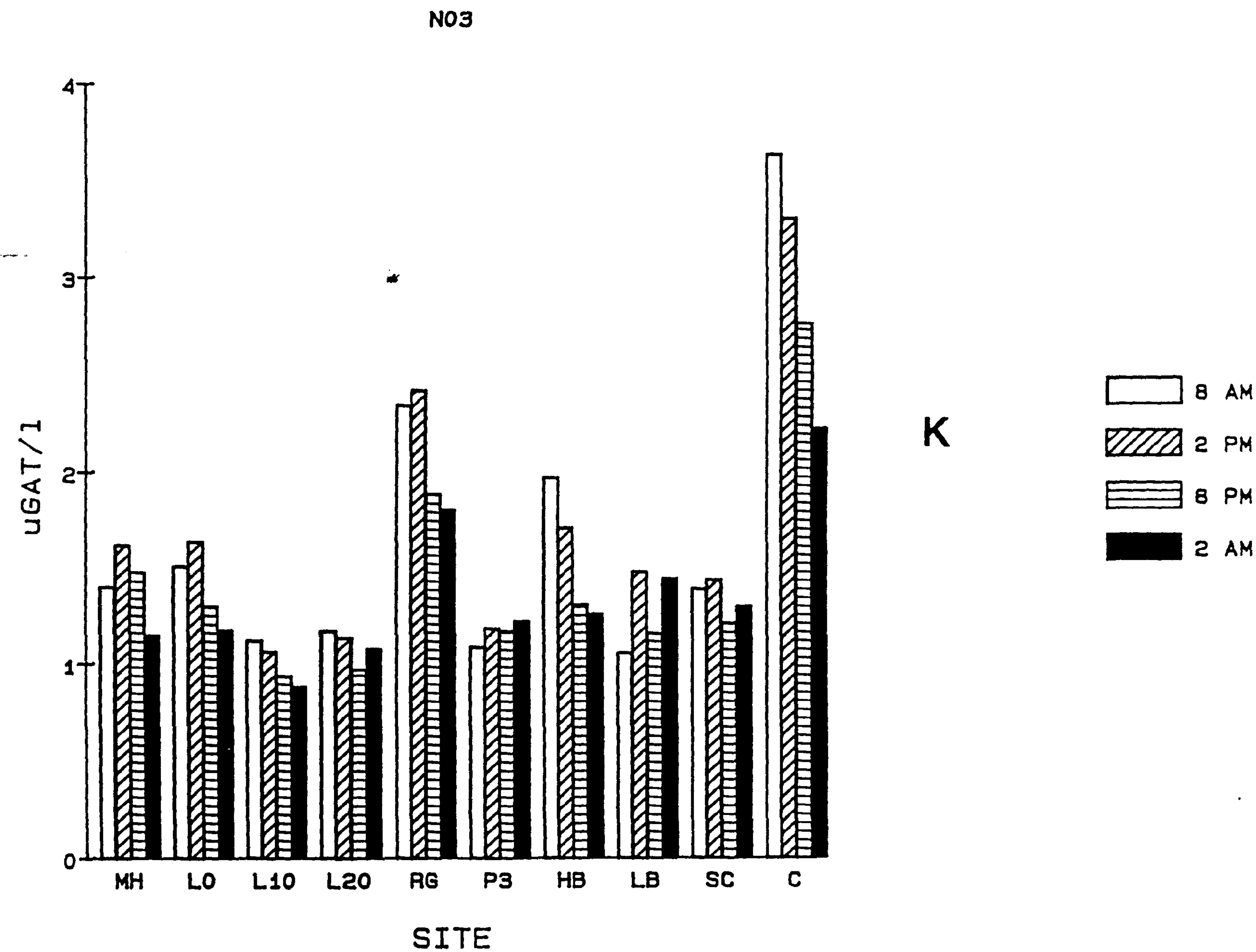
8 AM
2 PM
8 PM
2 AM


NO3
uGAT/1
0
1
2
3
4
MH
L0
L10
L20
RG
P3
HB
LB
SC
C
SITE
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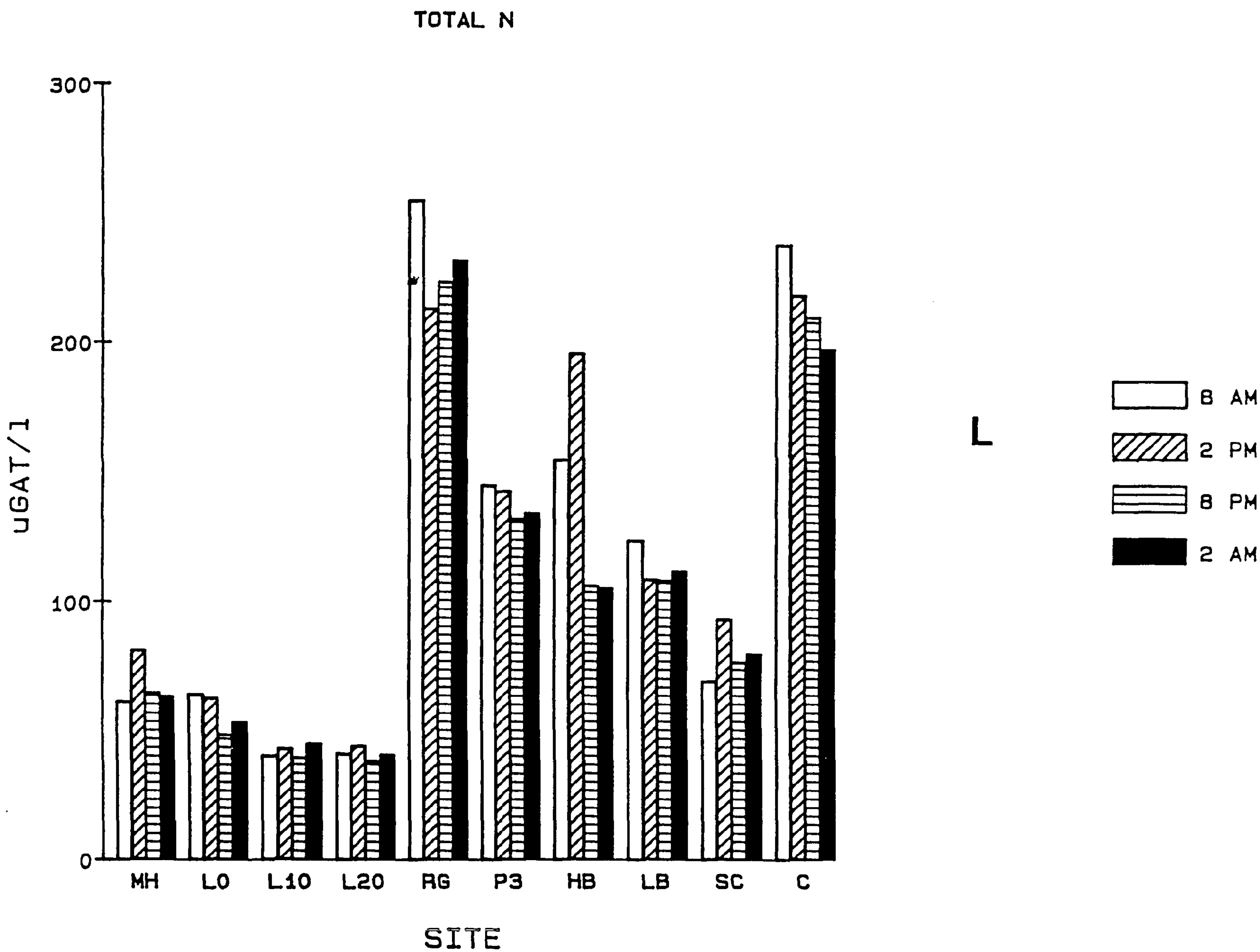
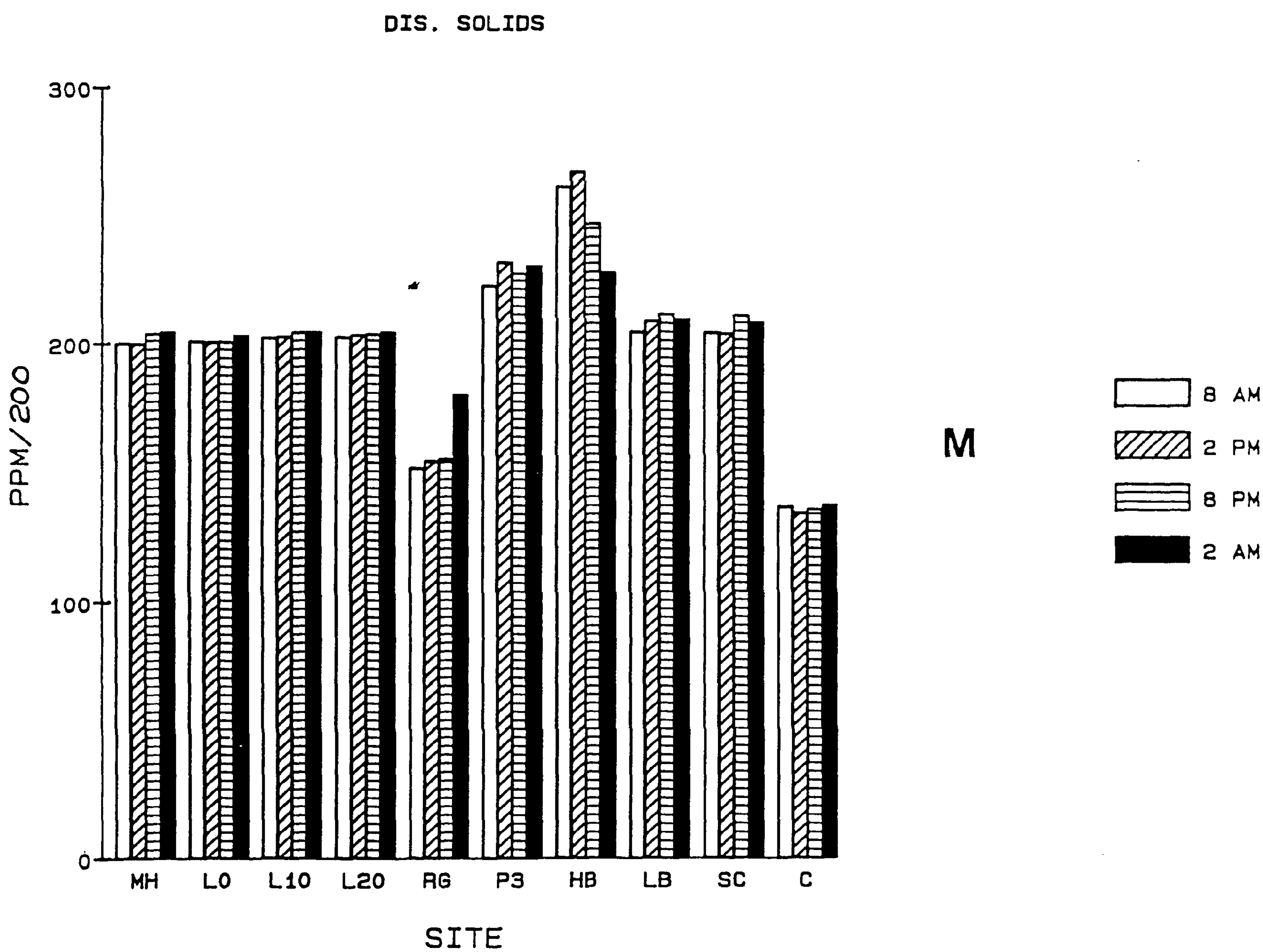
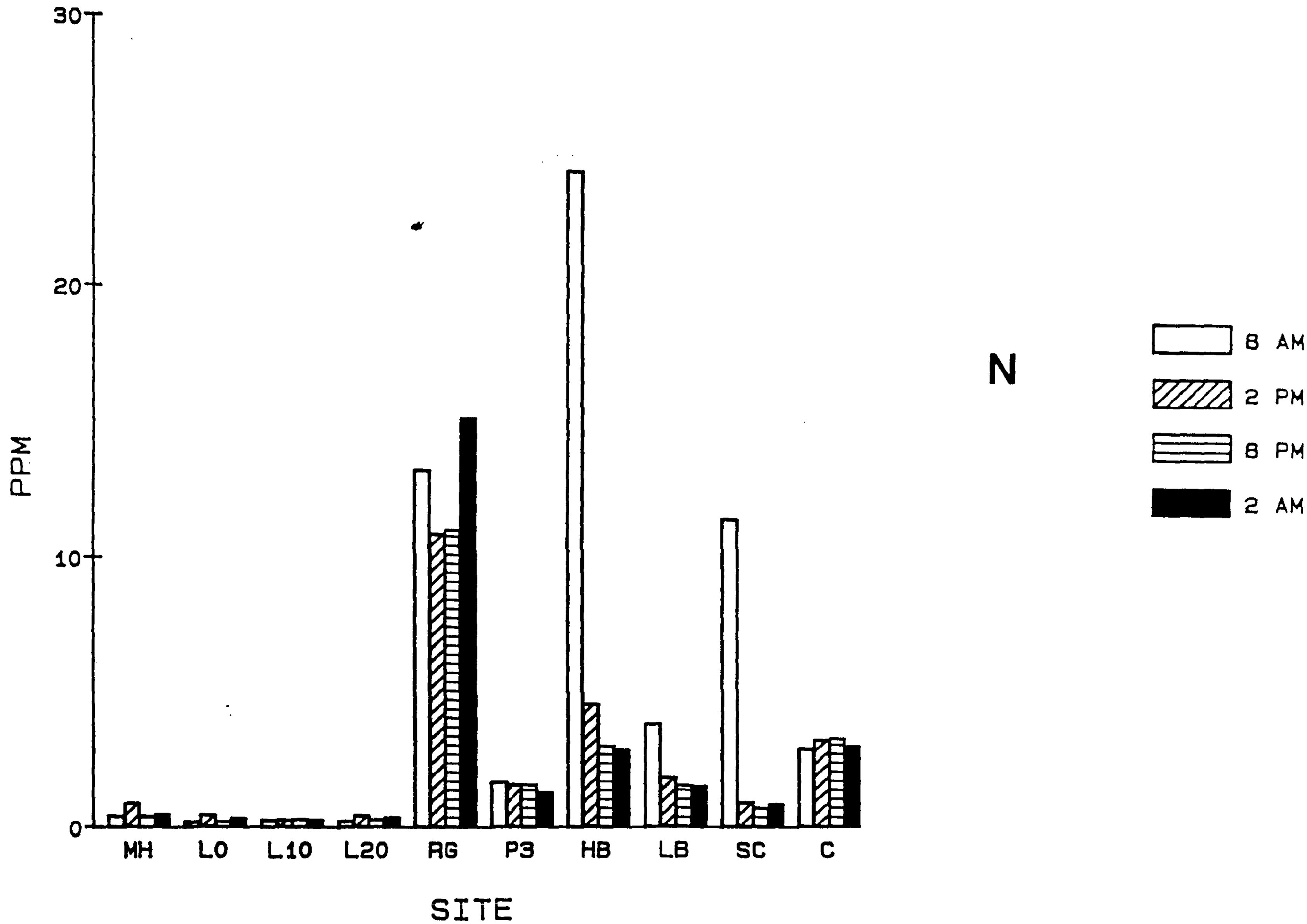
2 PM
8 PM
2 AM

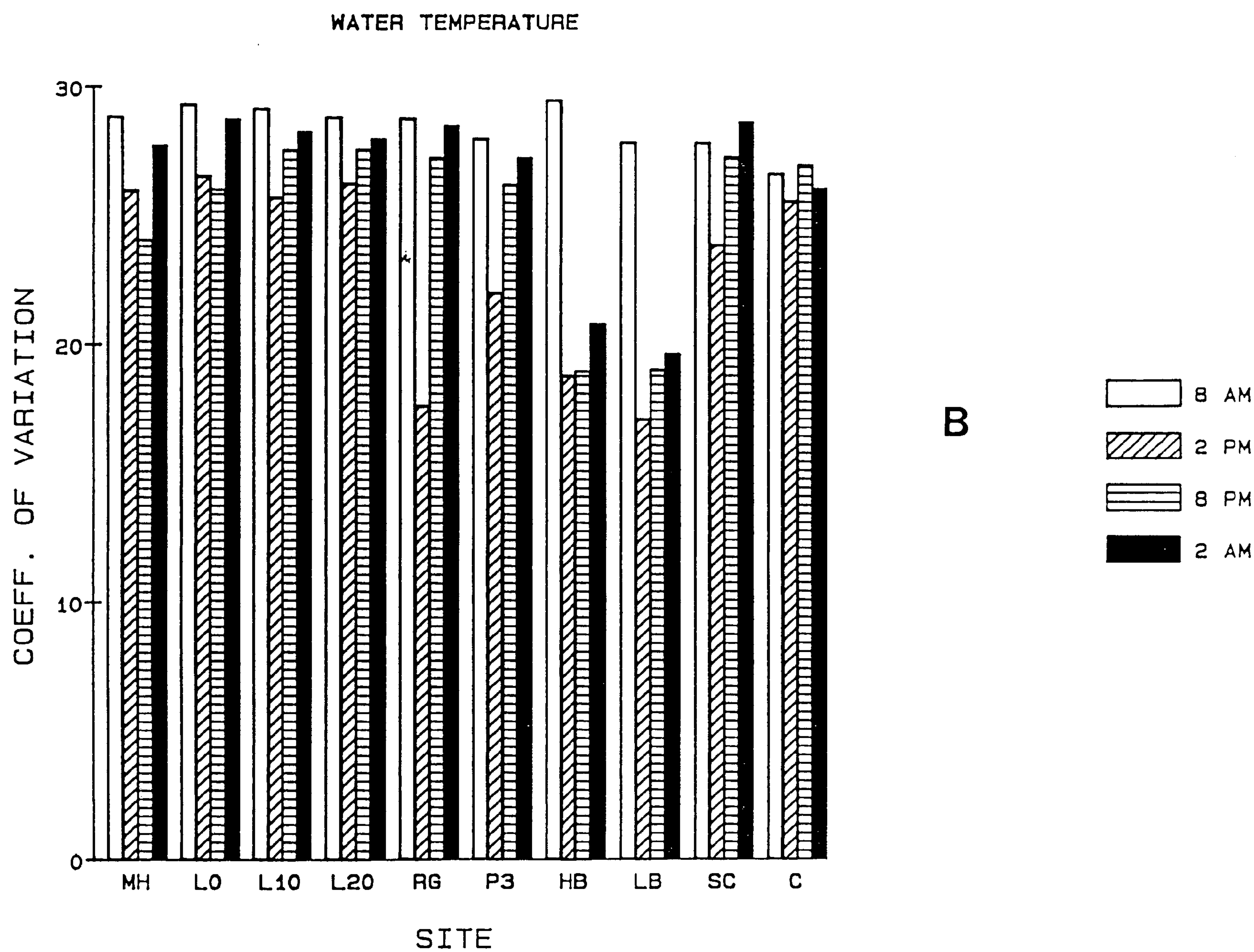
K


TOTAL N
300
200
100
0
uGAT/1
MH
L0
L10
L20
RG
P3
HB
LB
SC
C
SITE
L
8 AM
2 PM
8 PM
2 AM

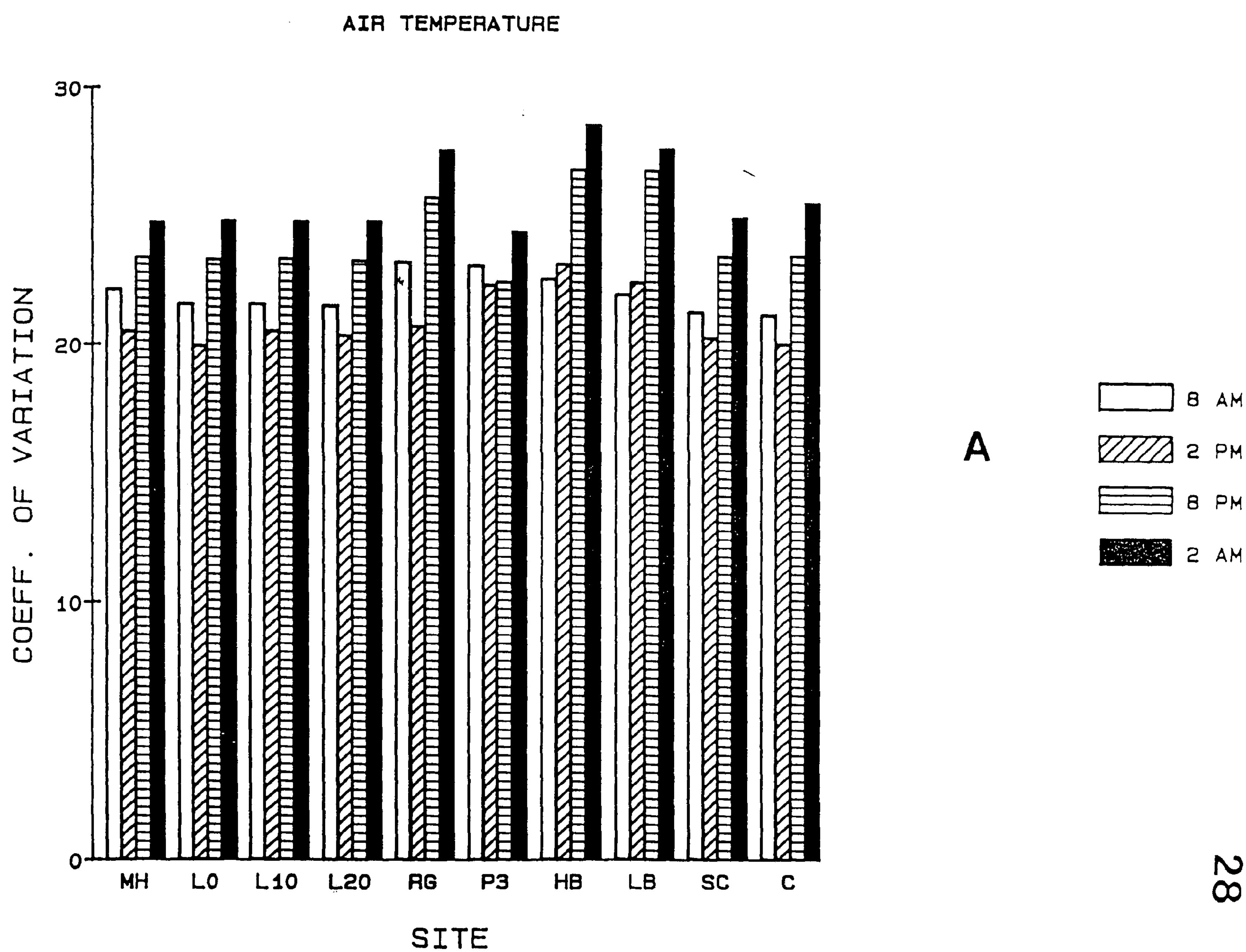

DIS. SOLIDS
300
200
100
0
PPM/200
MH
L0
L10
L20
RG
P3
HB
LB
SC
C
SITE
M
8 AM
2 PM
8 PM
2 AM

TANNIN-LIGNIN





WATER TEMPERATURE
COEFF. OF VARIATION
30
20
10
0
MH
L0
L10
L20
RG
P3
HB
LB
SC
C
SITE
B
8 AM
2 PM
8 PM
2 AM


AIR TEMPERATURE
COEFF. OF VARIATION
30
20
10
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MH
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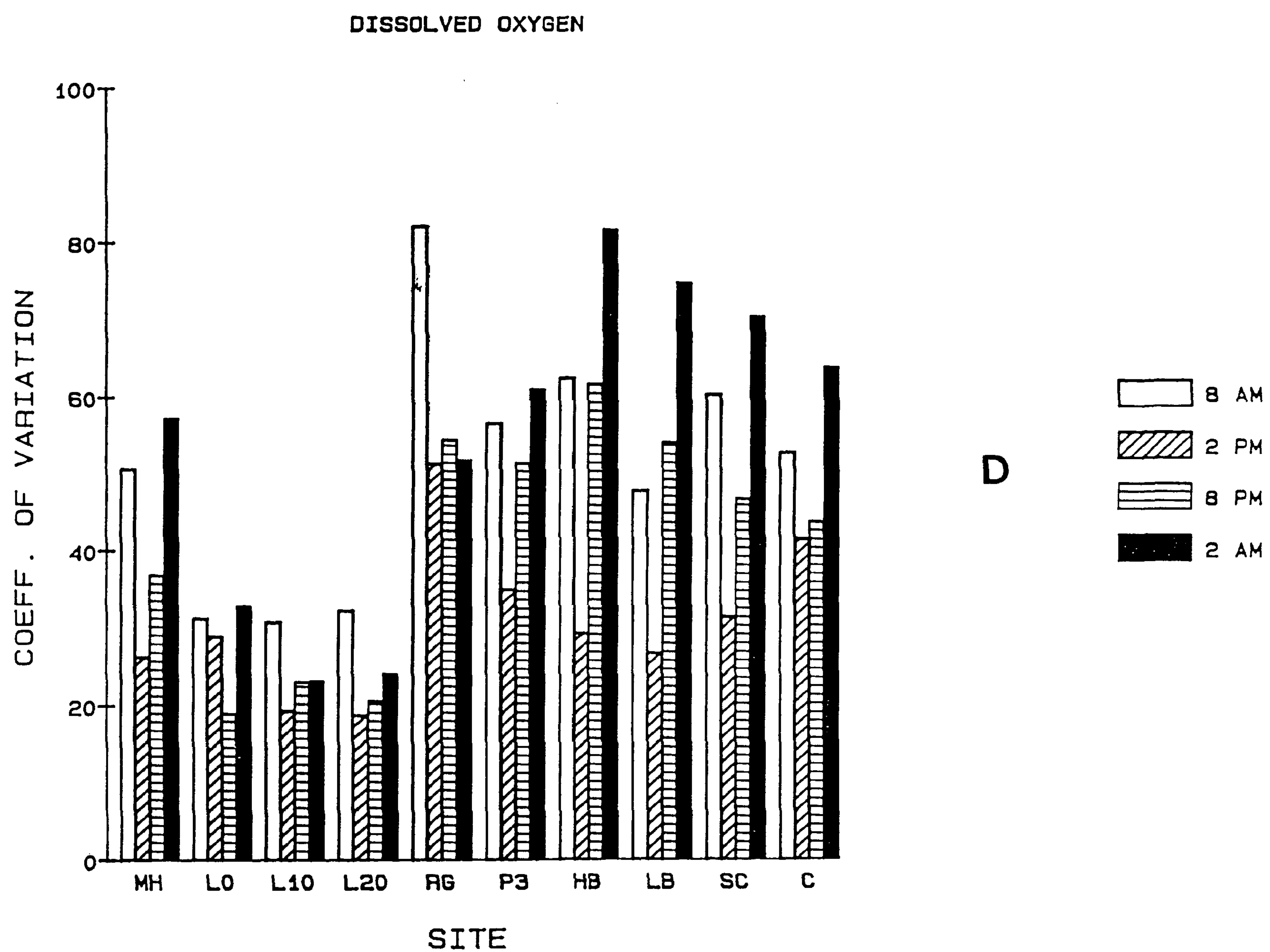
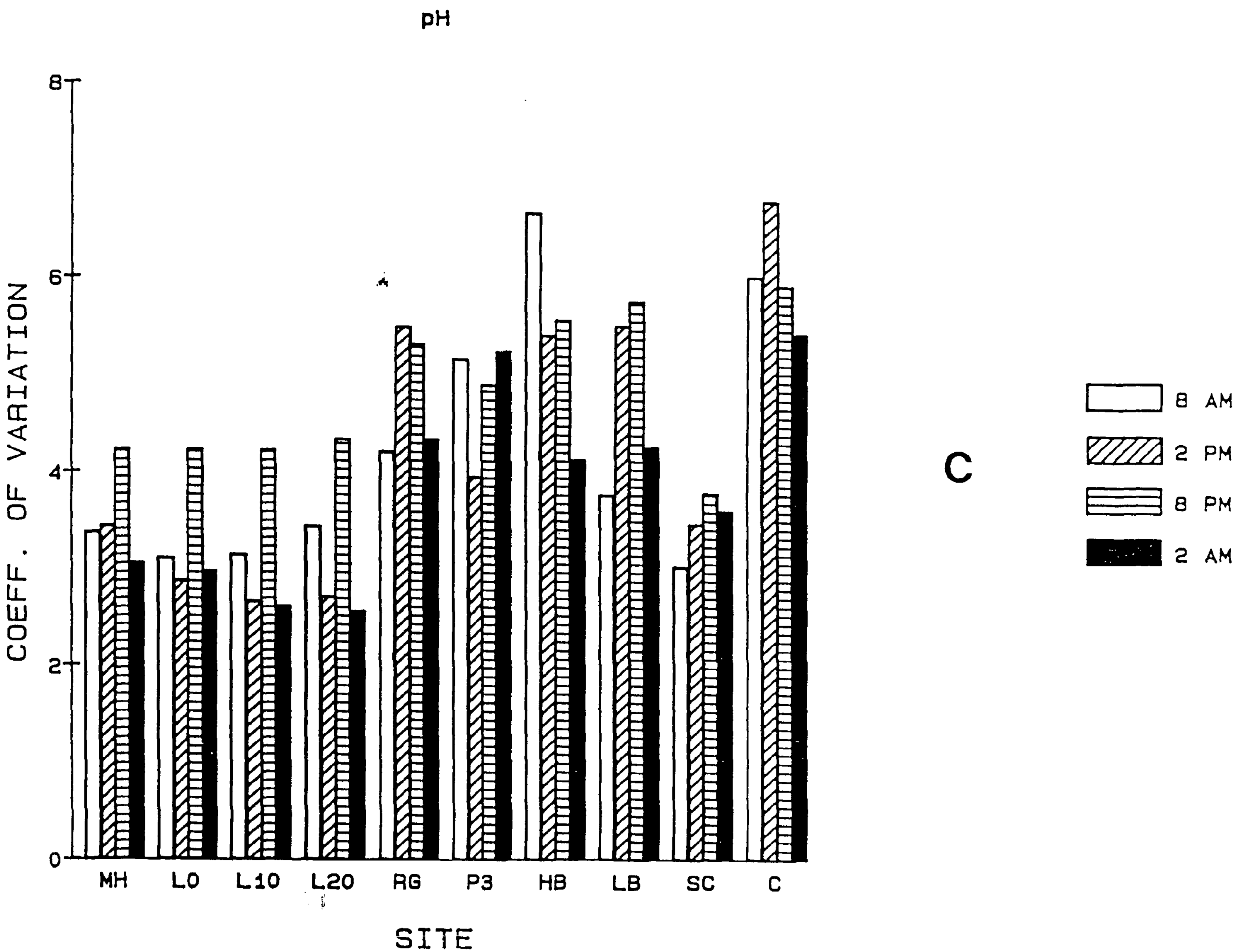
L10
L20
RG
P3
HB
LB
SC
C
SITE
A
8 AM
2 PM
8 PM
2 AM


DISSOLVED OXYGEN
COEFF. OF VARIATION
0
20
40
60
80
100
MH
L0
L10
L20
RG
P3
HB
LB
SC
C
SITE
8 AM
2 PM
8 PM
2 AM
D


pH
COEFF. OF VARIATION
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2
4
6
8
MH
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L10
L20
RG
P3
HB
LB
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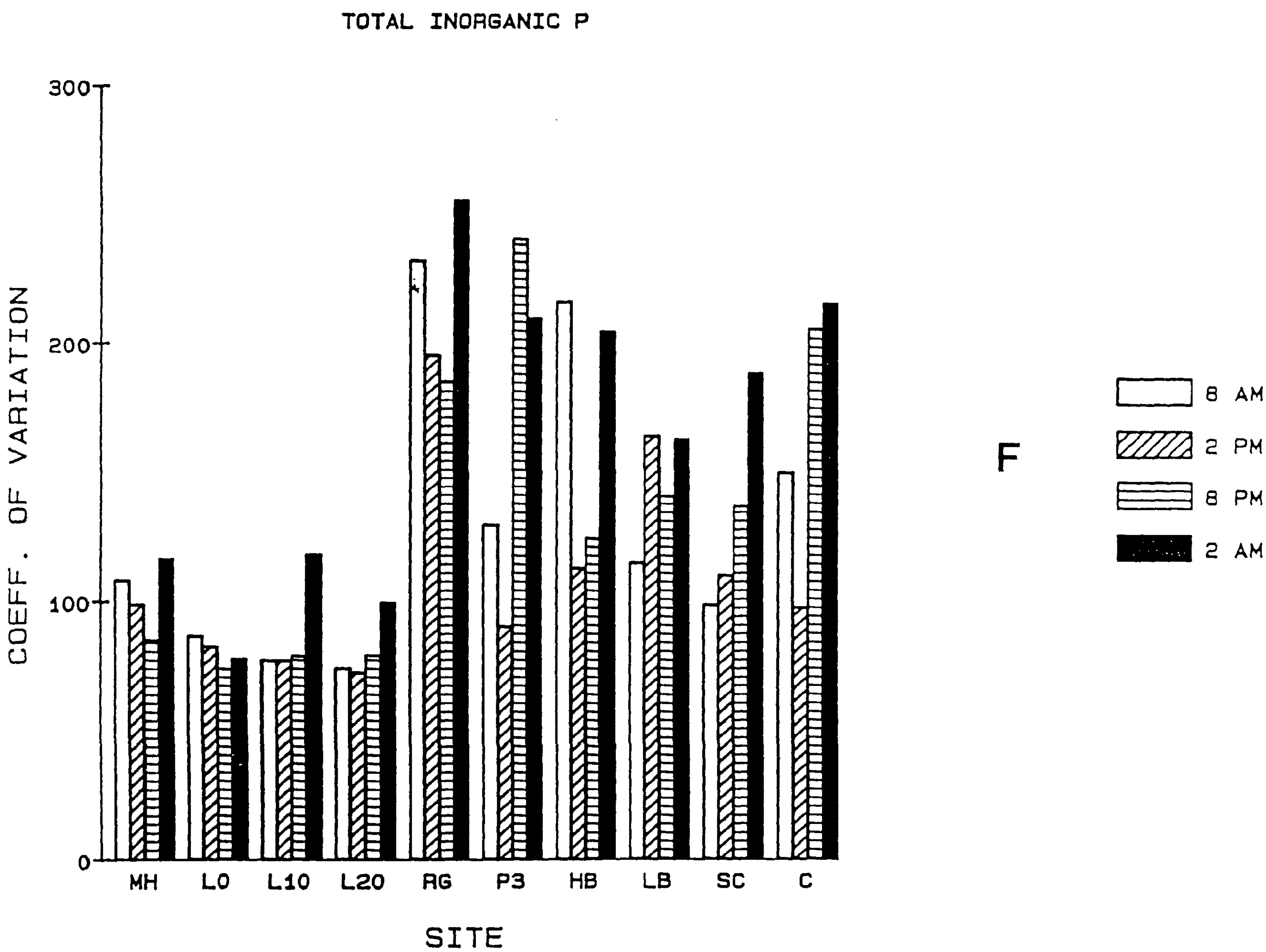
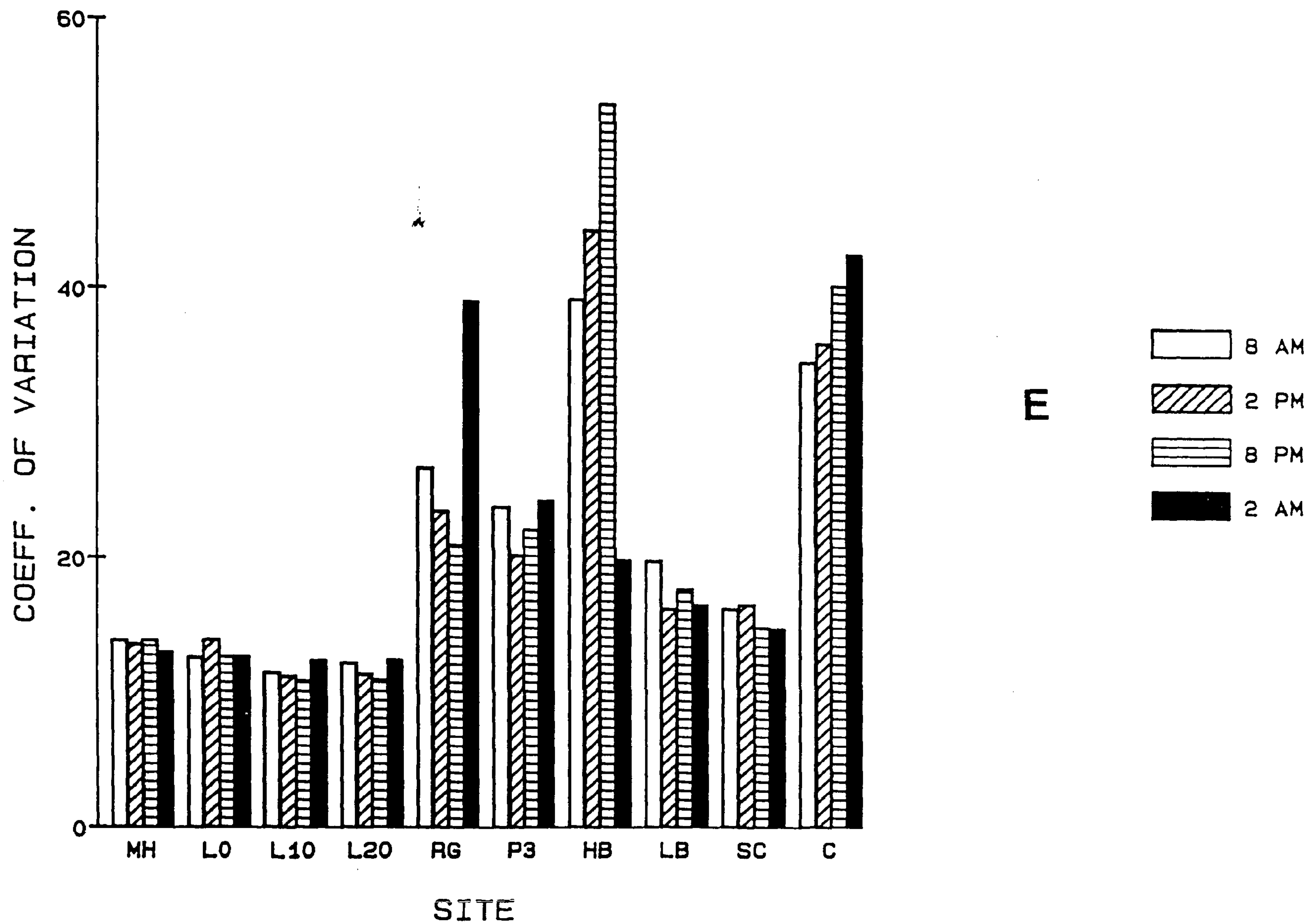
2 PM
8 PM
2 AM

C


TOTAL INORGANIC P
COEFF. OF VARIATION
300
200
100
0
MH
L0
L10
L20
RG
P3
HB
LB
SC
C
SITE
8 AM
2 PM
8 PM
2 AM

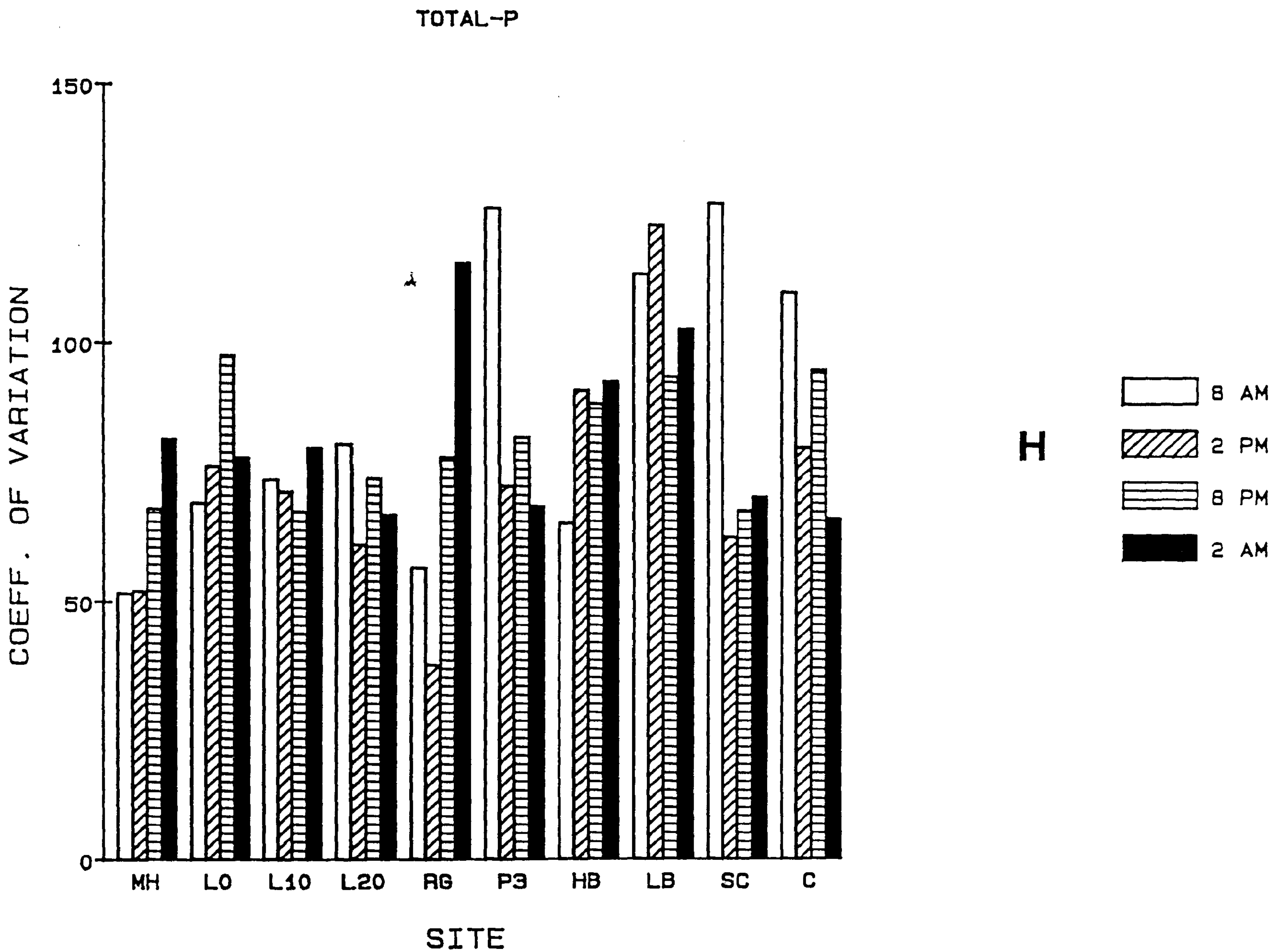
F

SALINITY



COEFF. OF VARIATION
0
20
40
60
MH
L0
L10
L20
RG
P3
HB
LB
SC
C
SITE
8 AM
2 PM
8 PM
2 AM

E



TOTAL-P
COEFF. OF VARIATION
150
100
50
0
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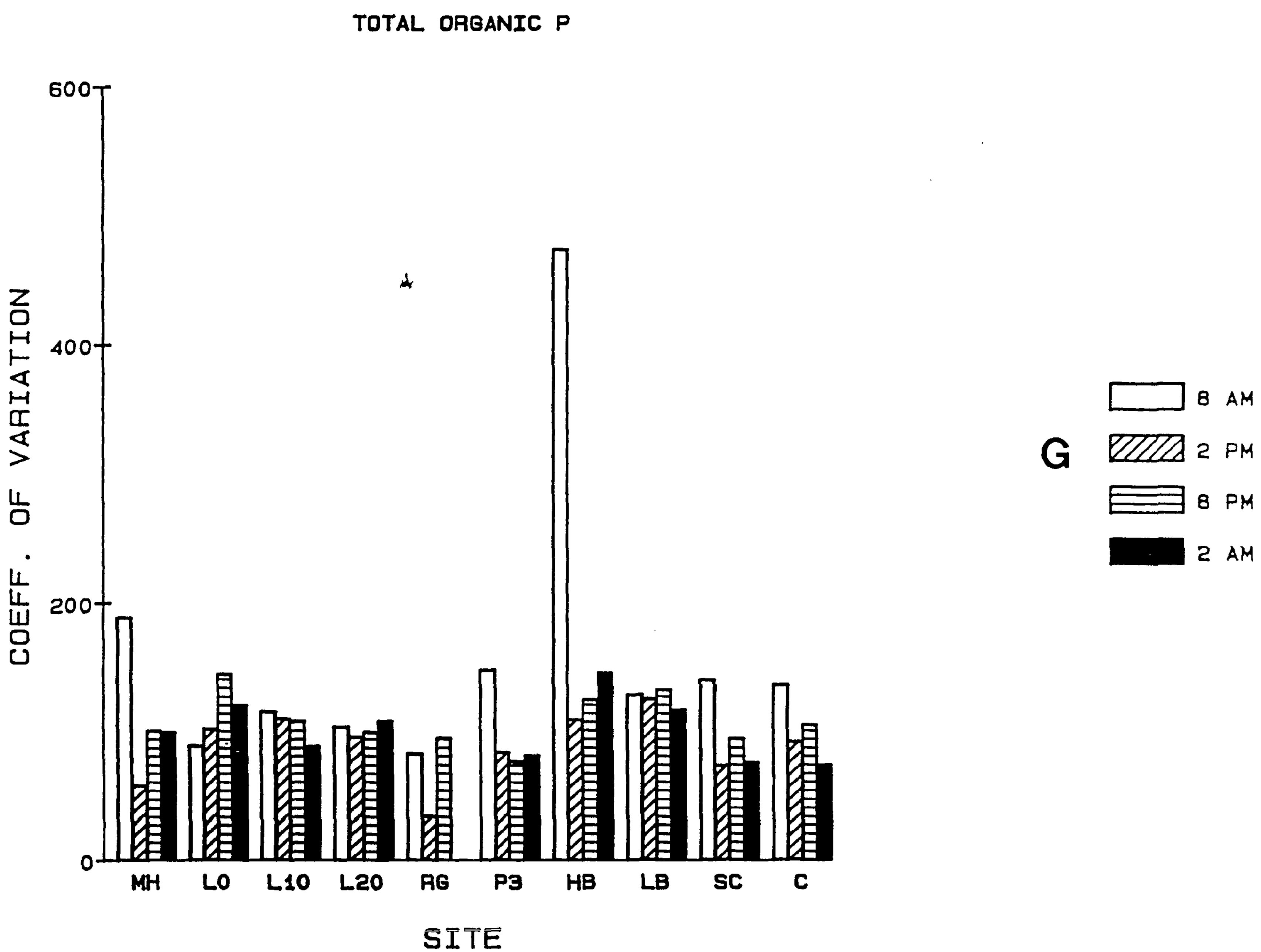
L0
L10
L20
RG
P3
HB
LB
SC
C
SITE
H
8 AM
2 PM
8 PM
2 AM



TOTAL ORGANIC P
COEFF. OF VARIATION
600
400
200
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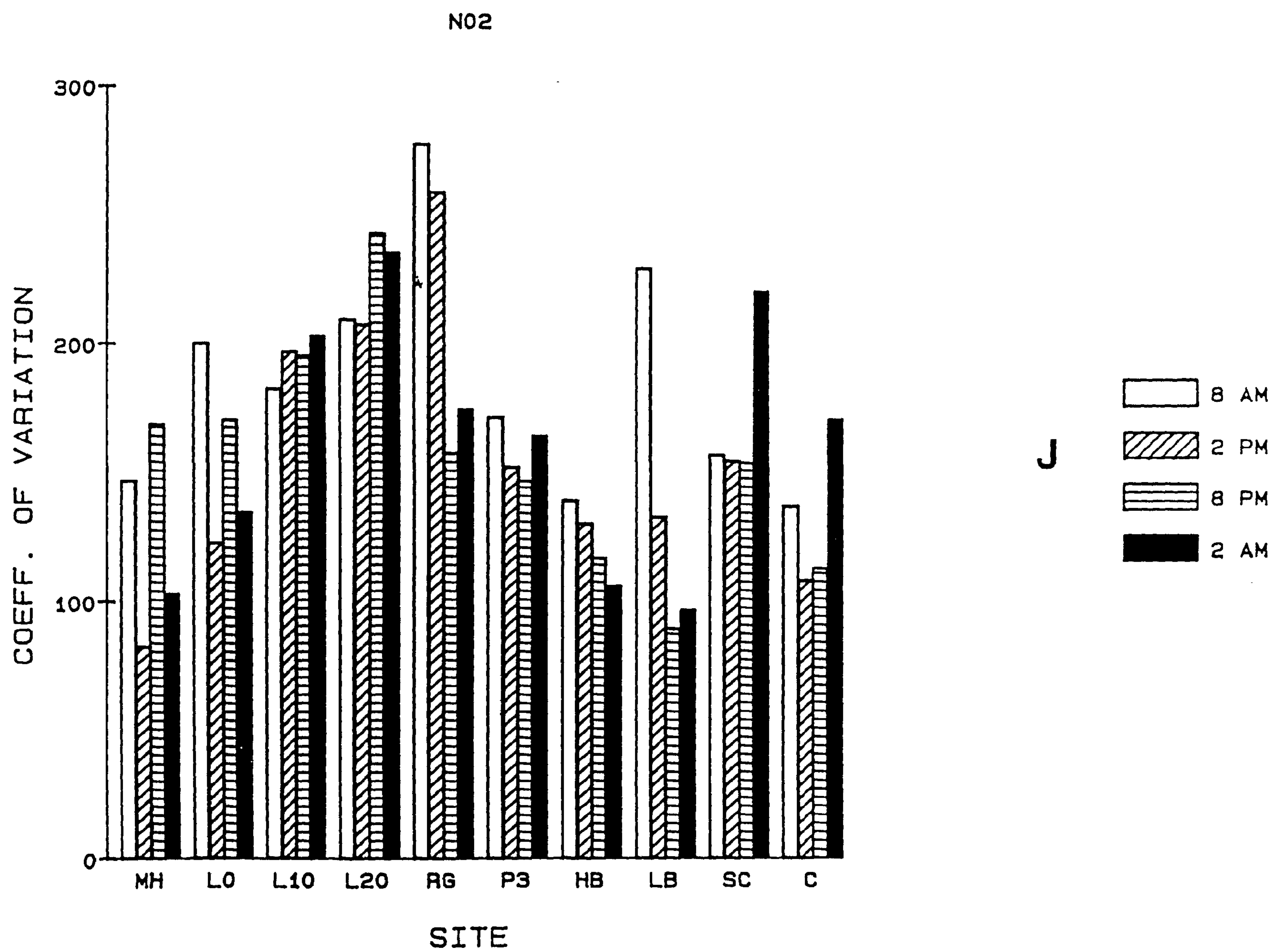
L0
L10
L20
RG
P3
HB
LB
SC
C
SITE
G
8 AM
2 PM
8 PM
2 AM



NO2
300
200
100
0
COEFF. OF VARIATION
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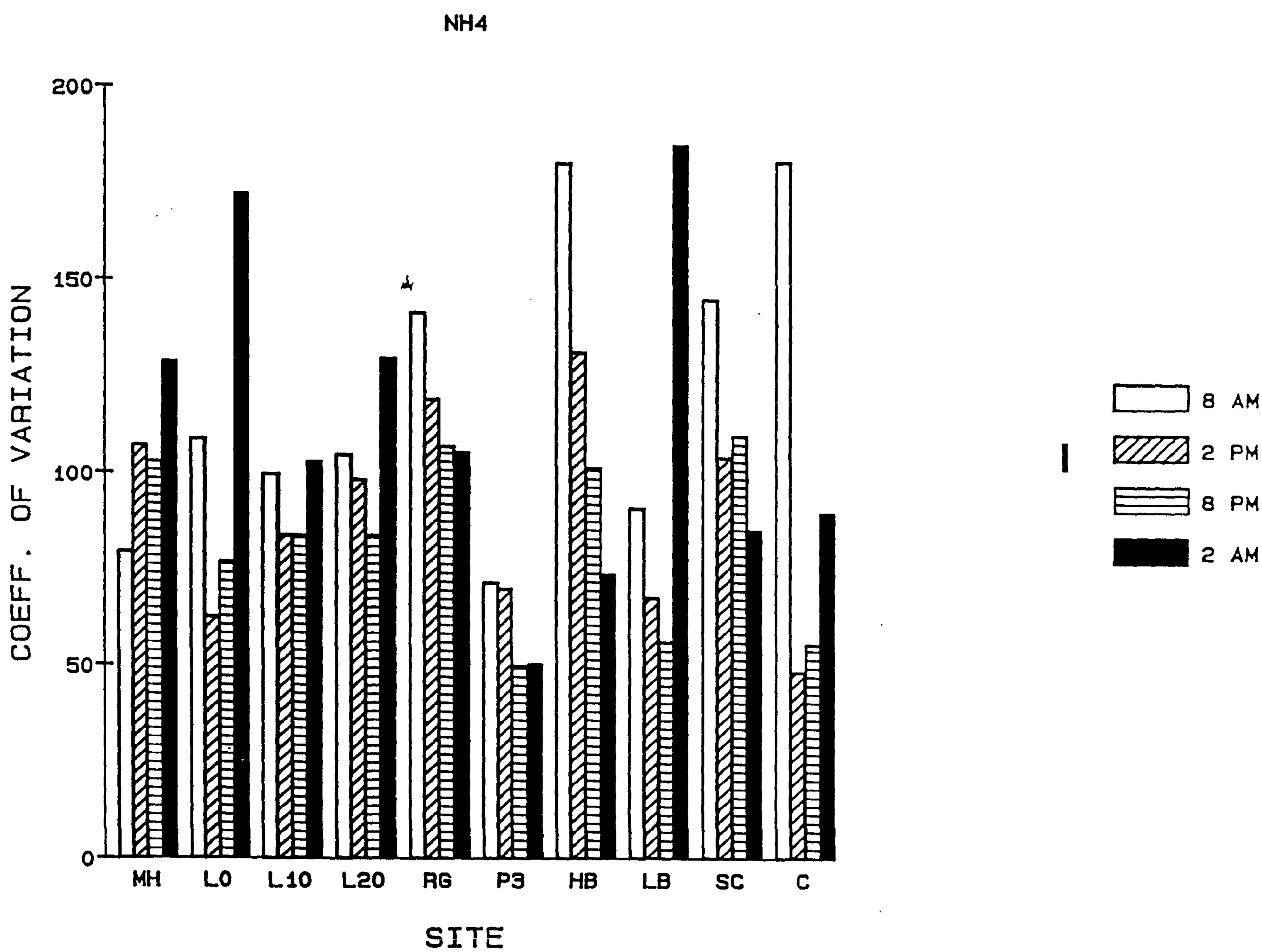
L0
L10
L20
RG
P3
HB
LB
SC
C
SITE
8 AM
2 PM
8 PM
2 AM

J



NH4
200
150
100
50
0
COEFF. OF VARIATION
MH
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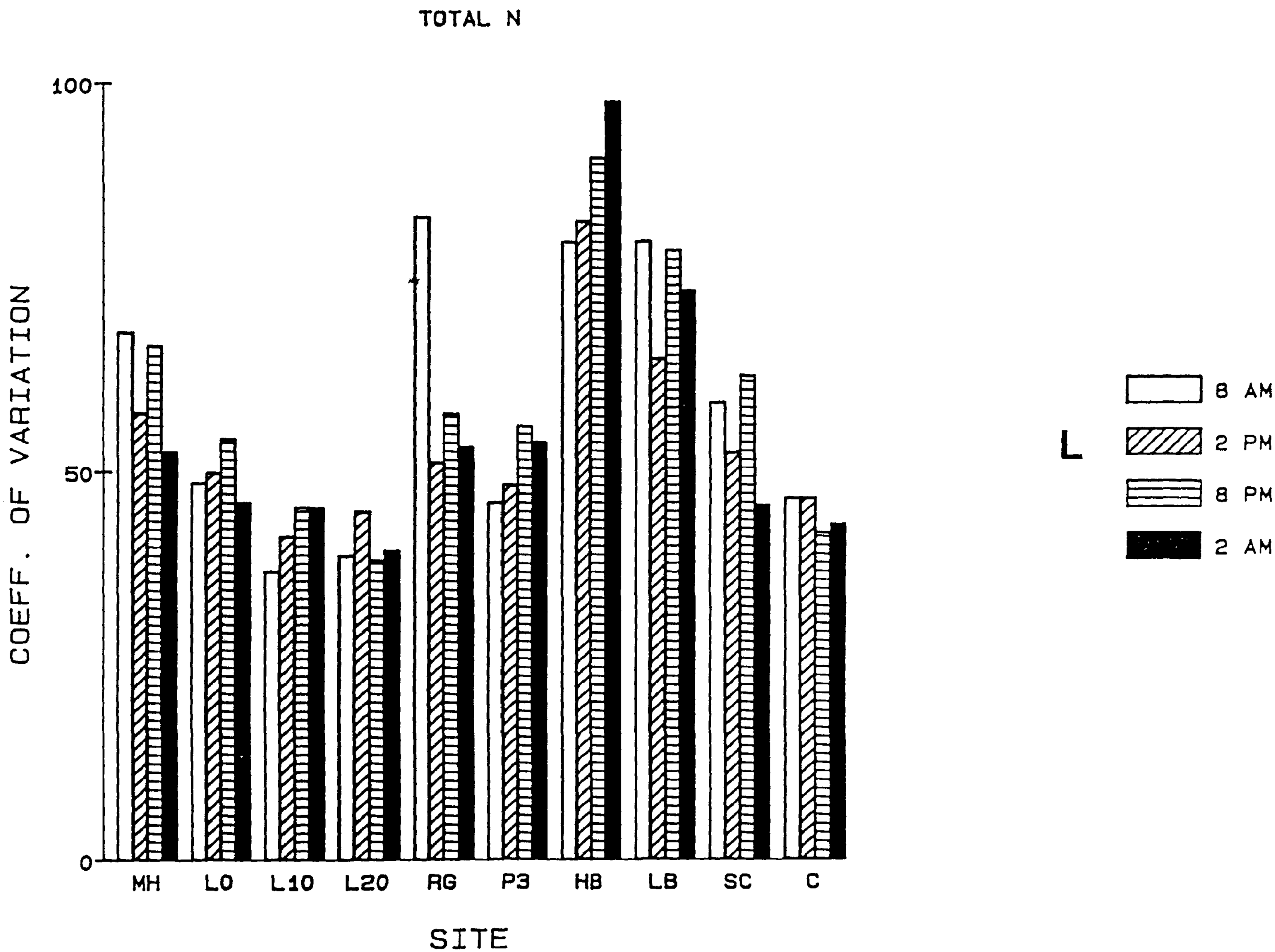
L10
L20
RG
P3
HB
LB
SC
C
SITE
8 AM
2 PM
8 PM
2 AM


TOTAL N
COEFF. OF VARIATION
100
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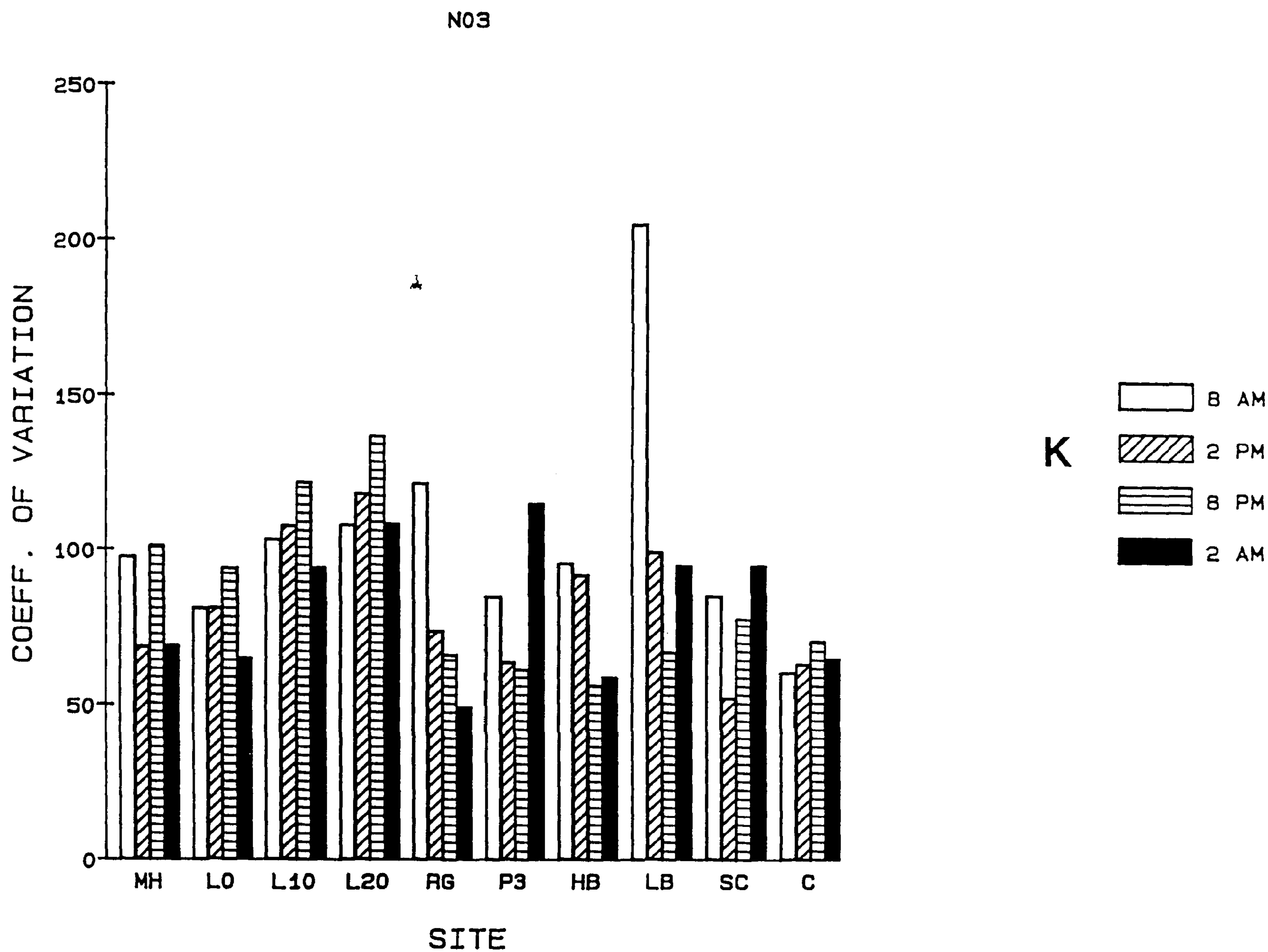
MH
L0
L10
L20
RG
P3
HB
LB
SC
C
SITE
L
8 AM
2 PM
8 PM
2 AM



N03
COEFF. OF VARIATION
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100
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LB
SC
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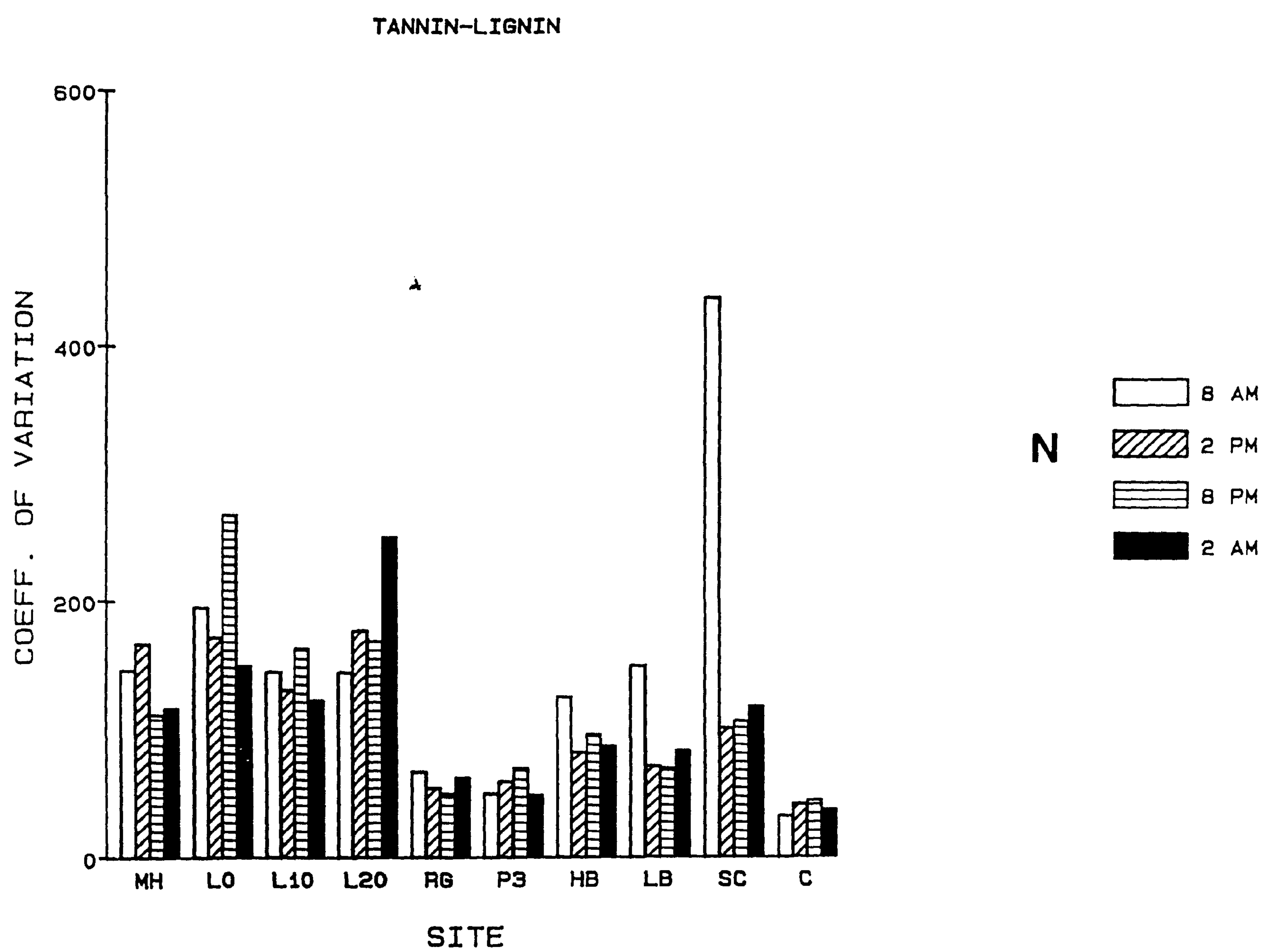
SITE
K
8 AM
2 PM
8 PM
2 AM



TANNIN-LIGNIN
COEFF. OF VARIATION
600
400
200
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L0
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L20
RG
P3
HB
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SITE
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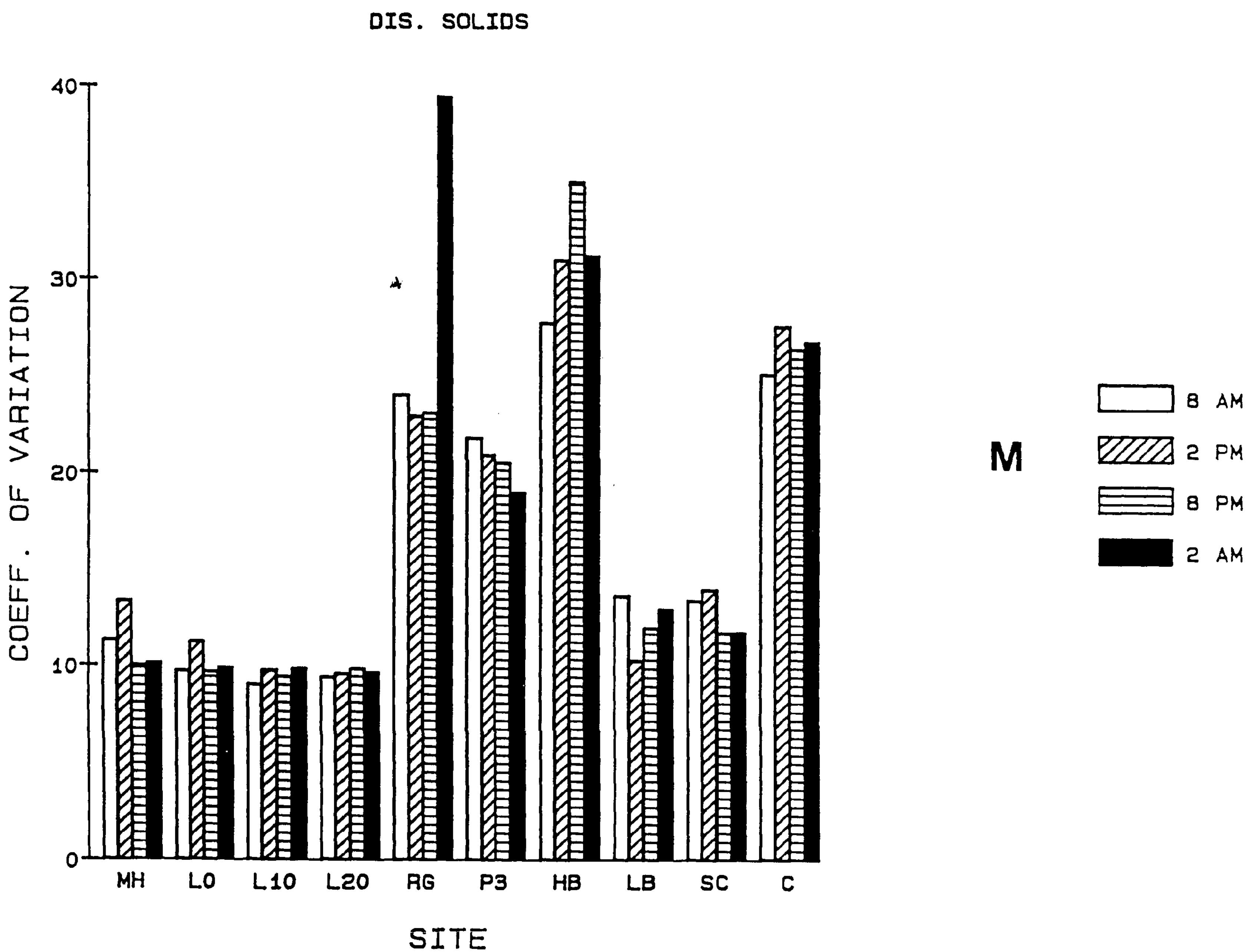
8 AM
2 PM
8 PM
2 AM


DIS. SOLIDS
COEFF. OF VARIATION
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10
20
30
40
MH
L0
L10
L20
RG
P3
HB
LB
SC
C
SITE
M
8 AM
2 PM
8 PM
2 AM

Table 2. Results of G-tests for changes in frequency by different species at the experimental site at comparable times of the year during 1982, 1983, and 1984.

	SPECIES							
COMPARISON	S. virginica	S. bigelovii	B. maritima	All	R. mangle	A. germinans	L. racemosa	All
SPRING								
1982-1983	0.000 -	26.671 ***	7.300 **	8.661 **	0.000 -	0.000 -	0.000 -	0.000 -
1982-1984	8.477 **	22.178 ***	5.020 *	18.351 ***	0.000 -	0.000 -	0.000 -	0.000 -
1982-1986	13.335 ***	7.659 **	2.076 -	8.661 **	0.000 -	0.000 -	1.375 -	0.337 -
1983-1984	8.477 **	2.635 -	0.674 -	2.918 -	0.000 -	0.000 -	0.000 -	0.000 -
1983-1986	13.335 ***	11.789 ***	2.076 -	0.000 -	0.000 -	0.000 -	1.375 -	0.337 -
1984-1986	5.499 *	8.477 **	0.674 -	2.917 -	0.000 -	0.000 -	1.375 -	0.337 -
SUMMER								
1982-1983	0.674 -	15.829 ***	1.912 -	15.123 ***	0.000 -	1.375 -	0.000 -	1.375 -
1982-1984	2.887 -	2.945 -	0.000 -	6.498 ***	0.000 -	1.375 -	0.000 -	0.337 -
1982-1985	5.020 *	5.189 *	0.674 -	15.828 ***	0.000 -	2.800 -	0.000 -	1.038 -
1983-1984	3.823 -	4.820 *	4.125 *	0.337 -	0.000 -	0.000 -	0.000 -	0.000 -
1983-1985	7.300 *	2.339 -	0.200 -	2.887 -	0.000 -	1.375 -	1.375 -	0.337 -
1984-1985	0.673 -	0.125 -	0.674 -	1.912 -	0.000 -	1.375 -	0.000 -	1.375 -
FALL								
1982-1983	5.020 *	10.999 ***	0.337 -	0.142 -	0.000 -	1.375 -	0.000 -	1.375 -
1982-1984	5.774 *	2.750 -	1.912 -	2.076 -	0.000 -	1.375 -	1.375 -	1.375 -
1983-1984	0.332 -	5.020 *	2.887 -	3.930 *	0.000 -	0.000 -	1.375 -	2.750 -
WINTER								
1983-1984	7.300 **	15.123 ***	4.125 *	17.873 ***	0.000 -	1.375 -	0.000 -	1.375 -
1983-1985	3.994 *	6.803 **	9.112 **	13.336 ***	0.000 -	2.773 -	1.375 -	4.125 *
1984-1985	0.142 -	2.750 -	0.000 -	0.000 -	0.000 -	1.386 -	1.375 -	2.750 -

* = p ≤ 0.05, ** = p ≤ 0.01, *** = p ≤ 0.001.

Table 1. Results of two-way analyses of variance for mean change in coverage per month by vegetation along the transect during 1983, 1984 and 1985. All data was transformed using the arcsine square root transformation to stabilize the variance.

SPECIES	FACTOR	F	P
S. virginica	Site	6.438	0.012
	Year	5.713	0.020
	Interaction	5.101	0.007
S. bigelovii	Site	0.298	0.586
	Year	26.058	$<$ 0.001
	Interaction	9.914	0.001
B. maritima	Site	0.296	0.587
	Year	7.324	0.001
	Interaction	4.529	0.012
R. mangle	Site	4.619	0.032
	Year	2.908	0.056
	Interaction	2.908	0.056
A. germinans	Site	13.122	0.001
	Year	0.303	0.739
	Interaction	0.844	0.431
L. racemosa	Site	3.045	0.082
	Year	4.661	0.010
	Interaction	5.666	0.004

Table 4. Results of Mann-Whitney Test for differences in monthly growth of mangroves in the two impoundments during each sampling interval.

	RED				BLACK				WHITE				ALL			
	N12	N24	W	P	N12	N24	W	P	N12	N24	W	P	N12	N24	W	P
3/82 8/82	21	27	876	***	70	45	3584	***	13	25	286	**	104	97	12961	***
8/82 11/82	20	26	366	*	68	45	2545	NS	13	24	214	NS	101	95	10157	***
11/82 3/83	17	26	315	*	68	43	2746	*	12	24	243	**	97	93	10429	***
3/83 5/83	16	25	388	**	64	44	2891	***	11	23	188	*	91	92	10526	***
5/83 8/83	15	26	380	**	67	46	3126	**	11	24	202	*	93	96	11191	***
8/83 11/83	9	25	201	**	41	40	1894	*	6	20	87	NS	56	85	7135	***
11/83 2/84	8	26	165	*	40	40	1810	NS	6	23	96	NS	56	89	7066	**
2/84 6/84	4	26	85	NS	43	40	2314	***	6	22	128	**	53	88	7890	***
6/84 8/84	4	26	-	-	42	40	1862	NS	6	24	120	*	52	90	7298	***
3/85 10/85	4	14	-	-	30	37	1409	NS	2	24	-	-	35	58	3087	*
TOTAL	21	27	930	***	72	46	3903	***	13	25	321	**	106	98	14253	***

* = $p \leq 0.05$, ** = $p \leq 0.01$, *** = $p \leq 0.001$, - = sample size too small for analysis.
N12 = Sample size for experimental cell, N24 = sample size for control.

Table 3. Results of G-tests for differences in frequency of different species at the control site at comparable times of the year during 1982, 1983, and 1984.

	SPECIES							
COMPARISON	S. virginica	S. bigelovii	B. maritima	All	R. mangle	A. germinans	L. racemosa	All
SPRING								
1982-1983	8.477 **	37.121 ***	0.501 -	7.300 **	0.000 -	1.912 -	6.874 **	9.624 **
1982-1984	22.980 ***	37.121 ***	3.823 -	14.601 ***	4.125 *	15.829 ***	10.999 ***	23.463 ***
1982-1986	19.581 ***	3.936 *	5.010 *	6.669 **	2.744 -	19.208 ***	6.860 **	26.068 ***
1983-1984	8.634 **	0.000 -	0.674 -	4.151 *	4.125 *	16.498 ***	1.912 -	14.578 ***
1983-1986	12.077 ***	19.208 ***	0.199 -	1.629 -	1.372 -	16.464 ***	2.744 -	17.836 ***
1984-1986	0.000 -	19.208 ***	0.199 -	0.284 -	0.000 -	2.071 -	0.000 -	1.315 -
SUMMER								
1982-1983	1.040 -	12.374 ***	7.300 **	0.000 -	0.337 -	1.912 -	3.930 *	5.020 *
1982-1984	45.370 ***	12.102 ***	6.146 *	26.122 ***	1.912 -	5.735 *	6.146 *	23.372 ***
1982-1985	26.050 ***	6.130 *	1.035 -	15.785 ***	2.879 -	10.968 ***	6.855 **	19.195 ***
1983-1984	36.481 ***	1.912 -	0.200 -	20.897 ***	5.499 *	3.114 -	0.674 -	10.880 ***
1983-1985	19.568 ***	1.035 -	0.672 -	15.785 ***	5.484 *	3.919 *	1.906 -	9.644 **
1984-1985	2.879 -	1.371 -	0.500 -	0.110 -	2.742 -	0.500 -	1.372 -	1.314 -
FALL								
1982-1983	19.248 ***	1.038 -	0.332 -	12.102 ***	0.000 -	3.114 -	0.674 -	7.859 **
1982-1984	35.168 ***	0.337 -	3.944 *	14.601 ***	1.317 -	9.671 ***	0.200 -	16.498 ***
1983-1984	14.601 ***	0.200 -	12.374 ***	1.149 -	1.912 -	2.076 -	0.142 -	0.399 -
WINTER								
1983-1984	23.372 ***	0.000 -	0.110 -	7.300 **	2.750 -	9.671 *	6.146 **	10.040 **
1983-1985	46.731 ***	0.000 -	2.075 -	26.118 ***	1.911 -	17.868 ***	0.142 -	9.682 **

$* = p \leq 0.05$, $** = p \leq 0.01$, $*** = p \leq 0.001$.

Table 6. Results of flowmeter tests.

RUN NO.	FLOWMETER LOCATION	MESH SIZE (u)	LENGTH OF TOW (m)	NET EFFICIENCY (%)
1.	Inside	63	30.5	85.6
	Outside	63	30.5	72.8
2.	Inside	63	60.9	8.9
	Outside	63	60.9	56.1
3.	Inside	202	60.9	90.2
	Outside	202	60.9	47.6
4.	Inside	63	60.9	8.2*
	Outside	63	60.9	58.5*
5.	Inside	None	60.9	97.5*

* Mean of two observations from paired flowmeters.

Table 5. Percent mortality of mangroves at IRC #12 (E) and SLC #24 (C). Significance levels for differences in mortality at the two sites obtained from the arcsine test for the equality of two percentages. ~ indicates sample sizes too small for statistical analysis.

DATE	ALL		RED		BLACK		WHITE	
	E	C	E	C	E	C	E	C
1982								
March	-	-	-	-	-	-	-	-
August	1.9	2.0	4.5	3.6	1.4	2.1	0.0	0.0
November	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0 .0
1983								
March	3.8	1.0	9.5	3.7	1.4	0.0	7.7	0.0
May	7.8	0.0	15.8	0.0 *	5.6	0.0 *	8.3	0.0
August	1.1	0.0	6.3	0.0	0.0	0.0	0.0	0.0
November	21.5	1.0 ***	40.0	0.0 ***	17.9	2.2 **	18.2	0.0 **
1984								
February	20.5	1.0 ***	11.1	0.0 ~	20.0	2.2 **	33.3	0.0 **
June	8.6	1.1 *	50.0	0.0 ~	2.3	2.3	0.0	0.0 ~
August	1.9	1.1	0.0	0.0 ~	2.3	0.0	0.0	0.0 ~
1985								
March	26.9	11.8 ***	0.0	0.0 ~	23.8	0.0 ***	66.7	4.0 ~
October	0.0	11.8 ***	0.0	30.8 ~	0.0	7.0 *	0.0	0.0 ~
TOTAL	64.8	11.8 ***	81.8	35.7 ***	56.2	14.9 ***	84.6	4.0 ***
***								

* = p < 0.05, ** = p < 0.01, *** = p < 0.001.

Table 8. Spearman's correlation coefficient between mean density per taxon at all sites.. Significance of all coefficients < 0.001; $N = 65$.

	202u PUMP	202u NET	63u PUMP	63u NET
202u PUMP	-	0.79690	0.68261	0.68441
202u NET		-	0.72122	0.77691
63u PUMP			-	0.77854
63u NET				-

Table 7. Mean similarity between samples. Pump-net values compare the similarity between contemporary samples with the two gear types. Pump-pump values compare the similarity between replicate pump samples at the same site. JS = Jaccard, CZ = Czekanowski.

COMPARISON	SITE	CZ	JS
<u>Pump-Net</u>			
63u	Culvert	0.550	0.672
	Lagoon	0.321	0.627
	Control	0.518	0.437
	All	0.453	0.587
202u	Culvert	0.263	0.292
	Lagoon	0.329	0.359
	Control	0.463	0.335
	All	0.347	0.328
<u>Pump-Pump</u>*			
63u	Mole Hole	0.559	0.717

* Five consecutive samples.

Table 9. Density (indiv./m^3) of all taxa captured at the various sites with the 202u gear.

DATE	MOLE HOLE PUMP	MOLE HOLE NET	CULVERT PUMP	CULVERT NET	LAGOON PUMP	LAGOON NET	CONTROL PUMP	CONTROL NET
1982								
11-OCT	2422.8	-	631.8	367.8	758.1	1158.4	16.7	87.2
29-OCT	3932.8	-	48.8	142.0	6.1	83.5	4.8	14.3
10-NOV	277.2	-	15.7	63.7	23.9	67.8	10.4	19.9
23-NOV	64.6	-	89.4	-	178.8	-	76.9	-
10-DEC	565.3	-	9.3	98.0	10.4	56.2	92.5	73.4
21-DEC	294.4	-	17.4	44.0	14.5	74.4	171.4	100.3
1983								
6-JAN	97.0	-	133.4	433.2	54.8	285.1	12163.8	9103.8
19-JAN	185.5	-	23.2	145.6	52.0	218.5	13887.8	10.3
3-FEB	2350.7	-	1659.8	551.3	462.0	429.1	3369.4	-

Appendix A. List of taxa collected in the plankton samples.

SARCODINA	
Rhizopodea	Foraminifera
CILIOPHORA	
Polyhymenophora	Tintinnidae
CNIDARIA	
Anthozoa	Ceriantaria
	Anthozoa
Hydrozoa	Hydroids
ROTIFERA	
	Rotifers
NEMATODA	Nematodes
MOLLUSCA	
Gastropoda	Hydrobiidae sp. A
	Gastropod veligers
	Crepidula sp.
	Cerithidea scalariformes
Bivalvia	Bivalve veligers
ANNELIDA	
Polychaeta	Polychaetes
Oligochaeta	Oiligochaete sp. A
SIPUNCULIDA	Sipuncula sp.
ARTHROPODA	
Ostracoda	Ostracods
Copepoda	Acartia tonsa
	Tortanus setacaudatus
	Metis holothuriae
	Harpacticoid spp. B
	Scottolana canadensis
	Euterpina acutifrons
	Oithona nana
	Oithona colcarva
	Oithona copepodites
	Ergasilus sp.
	Cyclopoid sp. F
	Misc. nauplii
Cirripedia	Balanus sp.
Branchiura	Argulus sp.
Crustacea	Tanaid spp. (T)
	Spahaeroma sp. (I)
	Probopyrus pandalicola (I)
	Corophium lacustre (A)
	Corophium ellisi (A)
	Grandidierella bonnieroides (A)
	Gammarus mucronatus (A)
	Caprellid sp. A (A)
	Brachyuran zoea (D)
	Anomuran zoea (D)
	Shrimp larva A (D)
	Shrimp larva B (D)
	Palaemonetes pugio (D)

Crustacea (continued)	Palaemonetes intermedius (D)
	Hyppolite zostericols (D)
	Hyppolite pleuracantha (D)
Insecta	Collembola
	Odonata
	Hemiptera
	Coleoptera
	Diptera
	Hymenoptera
Arachnida	Spider sp. A
	Acarina
CHAETOAGNATHA	Saggita sp.
CHORDATA	
Ascidacea	Ascidean larvae
Larvacea	Oikopleura sp.
Osteichthyes	Micorgobius sp.
	Sygnathus scovelli
	Cyprinodon variegatus
	Gambusia affinis
	Poecilia latipinna
	Elops saurus
	Mugil cephalus
	Elops saurus
	Leptocephalus larvae
	Misc fish eggs
MISC.	Unknown sp. A
	Misc eggs.

C

CM 122

IMPOUNDMENT MANAGEMENT

MOSQUITO SAMPLING SECTION

SEPTEMBER 30, 1986

Douglas Carlson
Peter O'Bryan

Indian River Mosquito Control District
P.O. Box 670
Vero Beach, FL 32961-0670

I. INTRODUCTION.

The fourth year of this impoundment study has allowed the analysis of mosquito production from Indian River Impoundment No. 12 under a normal rotational impoundment management (RIM) scheme (i.e., seasonal flooding of the impounded high marsh from late spring to September by pumping with estuarine water to an elevation of approximately 1.0 ft. NGVD). Measurements of mosquito production under this RIM technique has allowed important comparisons with mosquito production during the marsh management techniques used in the first 3 years of this study: 1) free flow of water between the impounded marsh and estuary through culverts and, 2) passive retention of water with flapgate risers (Carlson and Vigliano 1985).

RIM is the impoundment management regime currently most favorably endorsed by managers of impounded high marshes along the central east-coast of Florida and by the Subcommittee on Managed Marshes (Carlson and Carroll 1985). RIM appears to allow for both mosquito control and natural resource enhancement considerations in impounded high marshes (Carlson, Gilmore and Rey 1985). CM 122 has provided the opportunity to quantify the effects of artificial flooding not only on mosquito production but on numerous marsh ecosystem components.

II. MATERIALS AND METHODS.

A. STUDY SITE.

Indian River Impoundment No. 12 has served as the study site during this entire four year study sequence. Constructed in March 1966 and located on the barrier island at the Indian River - St. Lucie County border, this 20.2 ha (50 acre) impoundment contains a perimeter ditch on 3 of the 4 impoundment sides (Fig. 1). The eastern edge does not contain a perimeter ditch and gently slopes into the upland. The marsh surface is primarily vegetated with Batis maritima (saltwort), Salicornia virginica (perennial glasswort), and Salicornia bigelovii (annual glasswort) with scattered black (Avicennia germinans), red (Rhizophora mangle) and white (Laguncularia racemosa) mangroves. There are many open unvegetated areas and ponds, some of which retain water all year long (Carlson and Vigliano 1985). During this final year of study but prior to culvert closure and estuarine pumping, the mosquito larvicides Altosid (methoprene) or diesel oil were applied on a need basis.

B. MOSQUITO SAMPLING METHODOLOGY.

The immature mosquito sampling technique used during the first three years of study (CM 47, 73 & 93) was continued during this fourth year of the research project (CM 122). The entire marsh surface was divided into 12 quadrats (Fig. 2). These unequally sized quadrats were designated North A,B,C, West A,B,C, South A,B,C and East A,B,C. On each twice weekly sampling visit, mosquitoes were sought out in all quadrats. No areas were neglected but through experience those vegetated areas shown to produce mosquitoes were most thoroughly examined. When larvae were found, random sampling with five 350 ml dips were taken per quadrat (Carlson and Vigliano 1985). In this report, brood size is expressed as mean number per dip in a quadrat.

C. WATER MANAGEMENT TIMETABLE DURING CM 122.

October 1, 1985 (beginning of CM 122): Both culverts open to free flow of water between marsh and estuary.

May 16, 1986: Flapgates installed in both north and south culverts trapped tidal water which had entered the marsh during the previous week.

May 19, 1986: Elevations were established at both culverts and a riser board to establish the 1.0 ft. NGVD elevation was placed in the south culvert. Water continued to flow into the impoundment during the entire week.

May 28, 1986: The impoundment flooding level was several inches below the 1.0 ft. NGVD elevation. Water was pumped into the impoundment with the IRMCD portable pump for approximately 5 hrs. (11 AM - 4 PM).

May 29, 1986: Water was pumped into the impoundment for an additional 4 hrs. (7:30 AM - 11:30 AM) when the flooding elevation of 1.05 ft. NGVD was reached.

June 4, 1986: Because the impoundment water level had dropped to 0.8 ft. NGVD. Estuarine water was pumped into the impoundment for approximately 7 hrs. to bring the flooding elevation back to 1.0 ft.

September 16, 1986: The flapgate risers from both culverts removed to allow free flow of water between the impounded marsh and estuary.

D. PUMPING, CULVERT ALIGNMENT AND SEPTEMBER IMPOUNDMENT OPENING INFORMATION.

1. PUMPING.

Because we were able to trap water which had entered the impoundment through high tides to an elevation of approximately 0.8 ft. NGVD, little pumping was necessary. Water was pumped into Impoundment No. 12 at the pump station located at the northwest of Quadrat North C with a portable 6000 gallon per minute diesel-driven pump. Rainfall and tidal inundation kept the impoundment water level at the desired elevation of approximately 1.0 ft. NGVD, minimizing the need for additional pumping. Reconstruction of the pump station by the Indian River Mosquito Control District (IRMCD) field crew was necessary before pumping commenced.

2. CULVERT ALIGNMENT (Fig. 2b).

NORTH CULVERT. Elevation determinations on May 19 showed that the north culvert, which was placed in the impoundment on September 27, 1983, had shifted slightly. Originally it was installed at an invert elevation of approximately -0.8 ft. NGVD. However, our measurements in May showed that the culvert on the riser side (inside the impoundment) had risen to -0.5 ft. NGVD while the culvert invert in the Indian River Lagoon had fallen to -1.0 ft. NGVD. This means that with the flapgate in place, the riser elevation was 1.44 ft. NGVD.

After the impoundment was pumped, the riser rose several inches higher. This was not an unexpected occurrence. Similar floating action has been previously observed in other impoundments after a culvert and riser has been sealed off and the impoundment flooded. The water control structure which during the summer is essentially filled with air acts like a boat hull creating floatation pressure. Because mosquito control agencies are aware of this, when culverts with risers are now installed, they are usually placed up tight to the dike to minimize this floatation tendency. In some cases, the dike is even notched to allow the riser to fit snugly against the dike.

SOUTH CULVERT. At the south culvert, a board was placed on the riser to reach the required flooding level of approximately 1.05 ft. NGVD. During the summer, water frequently overflow the riser of this south culvert but did not flow out over the north culvert.

3. SEPTEMBER 1986 IMPOUNDMENT OPENING.

As described in the WATER MANAGEMENT TIMETABLE, the culverts were opened on Tuesday, Sept. 16, 1986. Because we were interested in documenting any obvious adverse effects on the estuary of this impoundment opening, daily observations and water sampling (for possible future analysis) was conducted on Monday, Sept. 15 (the day prior to opening) and each day through Friday, Sept. 19 both within the impoundment and in the adjacent lagoon. No adverse effects were readily apparent from this opening event. However on September 26, when decreasing lagoonal water levels caused a drying of the marsh with a subsequent concentration of fish in the perimeter ditch, a fish kill of resident species (predominately _Cyprinodon variegatus_ and _Poecilia latipinna_) was observed within the impoundment. Further observations and sampling for physical parameters early on September 27 indicated dissolved oxygen levels within the impoundment of <0.8 ppm and large fish mortality especially along the western bank approximately 200-400 meters north of the south culvert.

III. MOSQUITO PRODUCTION RESULTS (Table 1).

FIRST QUARTER
OCTOBER 1-DECEMBER 15, 1985.

During the first month and a half of this 2 1/2 month period when the impoundment was open to the estuary with both culverts, the marsh remained essentially flooded from the seasonal fall high tides and periodic heavy rainfall. Scattered _Anopheles_ spp. mosquitoes in the North and East quadrats were common during this period. In mid-November flooding elevations dropped below 1.0 ft. NGVD exposing portions of the marsh surface. Subsequent rain in December caused large _Aedes_ spp. broods in North A and East C.

OCTOBER 1-14 (rainfall=6.8 in.). During this two week period, observed water levels fluctuated from 1.2-1.6 ft. NGVD. These high tides and heavy rainfall kept the entire marsh surface flooded. Scattered _Anopheles_ spp. were collected in dips in East A,B,C, and North A,B,C.

OCTOBER 15-31 (rainfall=0.9 in.). The marsh remained completely flooded during this period with scattered _Anopheles_ spp. collected in East B,C, and North A,B,C. Water levels fluctuated between 1.2-1.6 ft. NGVD.

NOVEMBER 1-14 (rainfall=5.9 in.). Water levels dropped slightly during these two weeks despite heavy rainfall and ranged from 1.0-1.2 ft. NGVD. Again scattered _Anopheles_ spp. were collected in North A,B and East B.

NOVEMBER 15-30 (rainfall=0.9 in.). Observed water levels receded, ranging from 0.8-0.9 ft. NGVD. Even though there were exposed portions of the marsh surface, no mosquitoes were collected during this period because of very little rainfall.

DECEMBER 1-15 (rainfall=1.2 in.). Water levels remained quite constant at 0.7-0.8 ft. NGVD. This resulted in exposure of the north and east marsh surface edge. Approx. 1 in. of rain then caused large _Aedes_ spp. in North A ($\bar{X}$/dip=66.6) and East C ($\bar{X}$/dip=351.4) (Table 1) which were treated by hand. These conditions were very similar to those encountered last year when the impoundment was also open to the IR lagoon through the same two 18 in culverts. Water levels receded in mid-November followed by rainfall-induced mosquito breeding along the upland edges.

SECOND QUARTER
DECEMBER 16 - MARCH 15, 1986

Little mosquito activity occurred during the second quarter of sampling. Several mosquito broods were produced by rainfall in East C during this 3 month period but the sites typically went dry before adult emergence could occur. Observed water levels fluctuated greatly with especially low levels during the first two weeks of February (approx. 0.0 - 0.1 ft. NGVD). During this period the IRMCD field crew began to reinforce the existing pump station to prepare for use of the portable 6000 gpm pump. The recording flow meter was purchased and preliminary trials with it began at the south culvert.

DECEMBER 16-31 (rainfall=0.2 in.). During this two week period, observed water levels fluctuated from 0.34 to 0.75 ft. NGVD. These moderate flooding levels with little rainfall resulted in no mosquito production.

JANUARY 1-16 (rainfall=2.3 in.). Approx. 0.5 in. of rainfall resulted in a large mosquito brood in East C ($\bar{X}$/dip = 78.0) which was treated with diesel oil by hand. Water levels fluctuated greatly during this period from 0.20-0.82 ft. NGVD.

JANUARY 17-31 (rainfall=1.1 in.). High winds caused observed water levels to reach 0.67 ft. NGVD. A low of 0.08 ft. NGVD was observed. 0.8 in. of rain produced a mosquito brood in East C ($\bar{X}$/dip = 124.2) which was treated by hand.

FEBRUARY 1-15 (rainfall=0.5 in.). Observed water levels remained consistently low ranging from 0.0-0.1 ft. NGVD. Approx. 0.5 in. of rain produced a mosquito brood ($\bar{X}$/dip = 15.6) in East C which went dry before the mosquitoes could emerge.

FEBRUARY 16-28 (rainfall=0.25 in.). Strong winds and a full moon increased flooding levels to 0.72 ft. NGVD but the North and East quadrats which normally produce mosquitoes were not flooded. Low levels measured 0.16 ft. No mosquitoes were produced during this two week period.

MARCH 1-14 (rainfall=0.23 in.). Light rainfall produced mosquitoes only in bootprints in East C ($\bar{X}$/dip = 3.4). Observed water levels fluctuated from 0.08 to 0.50 ft. NGVD. These conditions are similar to those encountered last year when the impoundment was also open to the IR lagoon through the same two 18 in. culverts. In contrast to last year when mosquitoes were collected in very low numbers in January in North A, B and East B, C, this year several densely congregated broods were found only in East C during this several month period.

THIRD QUARTER
MARCH 15 - JUNE 15, 1986

Increased mosquito activity was observed during this third quarter primarily due to tidally induced mosquito breeding. In middle May, the two culverts were closed with flapgate risers, thus trapping water which had penetrated the marsh on the May spring tide. Pumping of Indian River Lagoon water into the impoundment with one of the Indian River Mosquito Control District's (IRMCD) portable diesel-driven 6000 gallon per minute (gpm) pumps followed several times for a total of 16 pumping hours (see WATER MANAGEMENT TIMETABLE above). This established the flooding level at the intended elevation of slightly over 1.0 ft. NGVD. Also during the past several months prior to culvert closure, the recording flow meter was set in the south culvert providing data on water flow velocities.

March 17-31 (rainfall = 4.2 in.). The flooding elevations during this period varied from 0.79-0.81 ft. NGVD. Strong NE winds, combined with a full moon and over 4 inches of rain, caused these levels which flooded much of the impoundment. Mosquito production resulted in 7 of the 12 quadrats. They were North A ($\bar{X}$/dip = 4.3), North B ($\bar{X}$/dip = 0.8), North C ($\bar{X}$/dip = 7.5), East B ($\bar{X}$/dip = 1.9), East C ($\bar{X}$/dip = 117.4), West A ($\bar{X}$/dip = 25.7) and West C ($\bar{X}$/dip = 104.0). These mosquito broods required an aerial application of Altosid.

April 1-16 (rainfall = 0.0 in.). Dry weather conditions combined with relatively low tides (observed range = 0.27-0.67 ft. NGVD) resulted in no mosquitoes during this two week period. April 17-30 (rainfall = 0.0 in.). Continuing dry weather and low river levels resulted in no mosquitoes during this two week period.

May 1-15 (rainfall = 2.8 in.). Almost 3 inches of rain combined with a tidal surge produced a mosquito brood in East C ($\bar{X}$/dip = 39.0) which was treated by hand. Observed flooding elevations ranged from 0.28 ft. to 0.96 ft. NGVD).

May 16-30 (rainfall = 0.2 in.). During this period high tides combined with the commencement of pumping, resulted in several broods in the East quadrats (East A: $\bar{X}$/dip = 9.0, East B: $\bar{X}$/dip = 1.2, East C: $\bar{X}$/dip = 635.8) which were treated by hand.

June 1-15 (rainfall = 1.4 in.). Water levels maintained by small amounts of rainfall and pumping on one occasion resulted in flooding elevations ranging from 1.13 - 1.44 ft. NGVD. Scattered <u>Anopheles</u> larvae were collected in East A,B,C and North A,B,C ranging from 1-15 per dip. Some <u>Anopheles</u> were collected on virtually every visit during this period.

FOURTH QUARTER
JUNE 16 - SEPTEMBER 30, 1986

Because sufficient intermittent rainfall kept the impoundment flooded to the 1.0 ft. NGVD level, estuarine pumping was not necessary during this entire 3 1/2 month period. Seasonal fall high tides matched the impoundment flooding level in early September. The flapgate risers were removed from both culverts on September 16 allowing free interchange of water between the marsh and estuary. As expected because of the continuous flooding, during this fourth quarter, no <u>Aedes</u> production occurred. Scattered <u>Anopheles</u> spp. were frequently collected along the East and North quadrats.

June 16-30 (rainfall = 1.2 in.). Impoundment water levels fluctuated between 1.15 and 1.22 ft. NGVD with a regular overflow of water over the south culvert riser. <u>Anopheles</u> spp. were collected at each sampling visit ranging from 1 to 6 per dip.

July 1-15 (rainfall = 2.1 in.). The impoundment water level ranged from 1.1 to 1.31 ft. NGVD with water flowing over the south culvert riser during most of this period. <u>Anopheles</u> spp. were collected on each visit and ranged from 1 to 14 per dip.

July 16-31 (rainfall = 5.1 in.). Considerable rainfall resulted in water levels ranging from 1.22 to 1.28 ft. NGVD during this period. Water was observed overflowing the south culvert on all sampling visits. Scattered <u>Anopheles</u> ranged from 1 to 4 per dip.

August 1-14 (rainfall = 1.5 in.). Water levels during this period remained high because of the continued rainfall input and ranged from 1.31 to 1.33 ft. NGVD with water flowing over the south culvert on all sampling visits. <u>Anopheles</u> were slightly less numerous during this period with a range of 1 to 7 when collected.

August 15-30 (rainfall = 5.6 in.). Rainfall kept water levels high (water levels ranged from 1.21 to 1.44 ft. NGVD) so that during this entire period water was flowing over the south culvert riser spilling into the lagoon. Only scattered Anopheles larvae were collected during this period with a maximum of 5/dip.

September 1-15 (rainfall = 2.7 in.). The first of the fall high tides began over the Labor Day Weekend resulting in water entering the impoundment through flapgates and over the riser. Water levels ranged between 1.13 and 1.55 ft. NGVD. Scattered Anopheles larvae were collected in the East and North quadrats but only as many as 1/dip.

September 16-30 (rainfall = 1.3 in.). Flapgates were removed on Sept. 16 when water levels measured 1.13 ft. NGVD. No mosquitoes were collected during this two week period as water levels dropped to 0.65 ft. NGVD and exposing much of the marsh surface.

SUMMARY AND COMPARISON OF MOSQUITO PRODUCTION FROM MAY TO OCTOBER UNDER DIFFERENT WATER MANAGEMENT REGIMES (Table 2).

OPEN WITH CULVERT(S)

OPEN WITH 1 CULVERT (1982). In 1982 when Impoundment No. 12 was open to the lagoon with 1-18 in. culvert, 37 mosquito broods were produced by 20 flooding events (tides or rainfall) in the North (A,B,C), East (B,C) and West (A,B,C) quadrats from May until the marsh was flooded by the seasonal high tides in mid-September (Carlson and Vigliano 1985). Mean monthly brood sizes ranged from 0.2 to 116.5/dip. By experimental design, this marsh was not chemically treated during this first year of study (CM 47).

OPEN WITH 2 CULVERTS (1985). In 1985, when the marsh was open with 2-18 in. culverts, 42 mosquito broods were produced by 14 flooding events in the North (A,B,C), East (B,C) and West (A) quadrats. Mean monthly brood sizes ranged from 0.2 to 443.5/dip. 10 aerial larvicide applications were necessary from May to October in 1985.

PASSIVE WATER RETENTION WITH FLAPGATE RISERS

1983-FLAPGATE RISER SET IN JULY (CULVERT OPEN IN MAY, JUNE TO MID-JULY). 7 mosquito broods were produced before the flapgate was placed in Culvert A. After flapgate placement only 3 broods were produced from North B & C by 7 flooding events. Mosquito production was essentially eliminated in the West quadrats during this period because those quadrats remained flooded (Carlson and Vigliano 1985). Mean monthly brood sizes ranged from 2.1 to 113.2/dip. One aerial larvicide treatment was necessary in August with several hand diesel treatments along the North and East quadrats to control localized mosquito production.

1984-FLAPGATE RISER SET IN JUNE (2 CULVERTS OPEN IN MAY). In May the impoundment was open to the lagoon with 2 culverts. During that month 6 broods were produced from 1 rainfall event in North A,B,C, East B,C, and West A. During the next 4 months, 27 broods were produced in the above-mentioned quadrats and also in West B,C, and South B by 7 flooding events. Mean monthly brood sizes ranged from 0.1 to 527.8/dip. Only 2 aerial larviciding treatments were necessary during the summer of 1984, but numerous ground applications were conducted for localized mosquito production along the East and North quadrats.

ROTATIONAL IMPOUNDMENT MANAGEMENT

1986-FLAPGATE RISERS PLACED IN MID-MAY FOLLOWED BY PUMPING OF ESTUARINE WATER INTO THE IMPOUNDMENT IN LATE MAY AND EARLY JUNE. In May, 3 broods were produced in East A,B,C from 2 tides and the initial pumping event. Mean monthly brood sizes ranged from 1.2 to 635.8/dip. For the next 4 months, no salt-marsh mosquito production was detected from Impoundment No. 12. Scattered <u>Anopheles</u> spp. were regularly collected along the North and East quadrats.

DISCUSSION

As expected, the management regime of open culverts to the lagoon resulted in the production of numerous and periodically very large mosquito broods from tides or rainfall (Carlson and Vigliano 1985). Passive water retention produced mixed results. In 1983, water retention with flapgate risers provided better control than 1982 (when the impoundment was open to the estuary) (Carlson and Vigliano 1985) but in 1984 numerous large mosquito broods were produced from the impoundment under this passive retention regime. Clearly, passive water retention under the conditions tested was an inadequate mosquito control method.

In contrast, estuarine flooding virtually eliminated salt-marsh mosquito production from Impoundment No. 12. The effectiveness of marsh flooding as a source reduction method has been verified previously (Clements and Rogers 1964). It is important to note that during the summer of 1986, when Impoundment No. 12 was flooded, IRMCD aerial larvicided an adjacent unmanaged impoundment (Oyster Bar-Impoundment No. 11) 5 times. In years past, both Impoundment No. 11 and No.12 usually require larviciding concurrently.

Although scattered <u>Anopheles</u> mosquitoes were common along Impoundment No. 12's edge, they appear to have occurred in insufficient adult numbers to cause a local nuisance problem. During 1986, field personnel never reported having been bitten by <u>Anopheles</u> adults. While it is possible that fluctuating water levels periodically produced salt-marsh mosquitoes along the impoundment edge, this was not detected by our intensive sampling work. It is possible that larvivorous fish controlled any such hatching salt-marsh mosquito larvae. However, fish did not eliminate Anopheles production. Therefore it is unlikely they would have done so for Aedes spp.

IV. REFERENCES CITED.

Carlson, D.B. and R.R. Vigliano. 1985. The effects of two different water management regimes on flooding and mosquito production in a salt marsh impoundment. Journal of the American Mosquito Control Association 1:203-211.

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Carlson, D.B., R.G. Gilmore and J.R. Rey. 1985. Salt marsh impoundment management on Florida's central east coast: reintegrating isolated high marshes to the estuary. In: Proceedings of the 12th Annual Conference on Wetlands Restoration and Creation, p. 47-63.

Clements, B.W. and A.J. Rogers. 1964. Studies of impounding for the control of salt-marsh mosquitoes in Florida, 1958-1963. Mosquito News 24:265-276.

V. CULVERT FLOW DETERMINATIONS.

A. EQUIPMENT. In April, a General Oceanics (Model 2031H) flow meter, flowmeter readout (Model 2035) and Cole-Parmer (Model 8377-15) mini-recorder were purchased and installed to measure water flow rates through culverts. This device was placed in the south culvert for several 24 hour periods prior to the commencement of pumping and in September after the flapgates were removed. Because the flowmeter only gives a visual display of flow velocity, the mini-recorder was necessary to obtain continuous data.

The mini-recorder has a range of voltage settings and therefore was easily adapted to the flowmeter readout. Through experimentation, we found that a voltage setting of 10 mV and a chart speed of 10 cm/hr provided an accurate recording of flow velocity and duration. The flowmeter itself was anchored by clipping a hook to the top of the culvert. A heavy lead weight anchored the bottom of it. This allowed the flowmeter to be situated exactly in the center of the culvert and swivel as the tidal direction changed.

B. RESULTS. Table 3 lists the measured flow rates and durations for several sampling periods. For both flood and ebb tides, the flow rate and duration varied widely, with longer flow durations having a higher maximum flow rate and shorter durations having a lower maximum velocity. Table 3 also shows the effect of the culvert trap when installed during the testing period. The trap cut flow velocities by 33% to 45%. The maximum flow velocity measured during the testing period was 1.2 m/sec. The lowest maximum velocity was 0.5 m/sec. The cross-sectional area of an 18 in culvert is 0.163 m2. At a maximum flow rate of 1.2 m/sec, this translates to a flow rate of 196 liters/sec or 51.58 gal/sec. This is slightly in excess of 3000 gal/min which is approximately half of the nominal capacity of the portable diesel-driven pumps used in Indian River County. However, this calculation does not take into account resistance caused at the pipe-water interface which is probably lowering overall flow amounts.

This information has provided insight into culvert flow characteristics at Impoundment No. 12 with the current 2-18 in. culvert configuration and will serve as baseline data for information collected during the upcoming year when comparisons of the effects of different culvert sizes will be studied.

VI. HI & LOW BREED VEGETATION COMPARISON OVER TIME (SUMMER 1985 VS. LATE SEPTEMBER 1986).

In early summer 1985, a detailed drawing of vegetative conditions in the Hi and Lo Breed locations was compiled and included in both the quarterly and final reports of CM 97. On September 25, 1986, we reevaluated vegetation at these two sites. Figures 3 & 4 show the 1985 sketch. Areas highlighted in yellow are those locations where vegetation was dead in late Sept. 1986. Overall, vegetative cover has decreased in both areas between these two observation periods.

VII. PRESENTATIONS, PUBLICATIONS AND RELATED RESEARCH DURING CM 122.

A. PRESENTATIONS.

1) Location: St. Johns River Water Management District, Palatka, Fla. (December 1985). Title: The impoundment management plan process and the Technical Subcommittee on Managed Salt Marshes (presentation by Douglas Carlson and Grant Gilmore).

2) Location: Annual meeting of the Entomological Society of America, Hollywood, Fla. (December 1985). Title: Managing south Florida salt marsh impoundments for mosquito control, fish and wildlife enhancement (poster presentation authored by Douglas Carlson, Grant Gilmore, Jorge Rey and Peter O'Bryan).

3) Location: Indian River Board of County Commissioners, Vero Beach, Fla. (February 1986). Title: Developing and implementing impoundment management plans benefiting mosquito control and natural resource enhancement (presentation given by Douglas Carlson and Grant Gilmore).

4) Results of this research project were thoroughly discussed with the staff of the Mosquito Research and Control Unit (MRCU), Grand Cayman, Cayman Islands, British West Indies during a trip to their country by Douglas Carlson from June 16-20. Doug Carlson was chosen by the Fla. Dept. of Health and Rehabilitative Services as part of a Florida mosquito control delegation to visit the Cayman Islands to observe their mosquito and marsh management techniques and make comparisons with techniques currently employed in Florida. MRCU has expressed interest in trying variations on rotational impoundment management in their country because of positive findings from this CZM project.

5) Location: Symposium on Waterfowl and Wetlands Management in the Coastal Zone of the Atlantic Flyway, Wilmington, Delaware (September 1986).

Title: Salt marsh impoundment management along Florida's Indian River Lagoon: historical perspectives and current implementation trends (presentation given by Douglas Carlson).

Title: Managing south Florida salt marsh impoundments for mosquito control, fish and wildlife enhancement (poster presentation authored by Douglas Carlson, Grant Gilmore, Jorge Rey and Peter O'Bryan).

B. PUBLICATIONS (COPIES INCLUDED).

1) "Developing and implementing impoundment management methods benefiting mosquito control, fish and wildlife: a two year progress report about the Technical Subcommittee on Mosquito Impoundments" by Douglas B. Carlson and Joseph D. Carroll, Jr., Journal of the Florida Anti-Mosquito Association (Volume 56, Number 1, 1985).

2) "Salt marsh impoundment management on Florida's central east coast: reintegrating isolated high marshes to the estuary", by Douglas B. Carlson, R.Grant Gilmore and Jorge R. Rey, Proceedings of the 12th Annual Conference on Wetlands Restoration and Creation, 1986, pp. 47-63.

3) "Salt marsh impoundment management along Florida's Indian River Lagoon: historical perspectives and current implementation trends" by Douglas B. Carlson, Proceedings of Symposium on Waterfowl and Wetlands Management in the Coastal Zone of the Atlantic Flyway, <u>in press</u>.

C. RELATED RESEARCH.

Concurrent with CM 122, the Fla. Department of Health and Rehabilitative Services (Office of Entomology) has funded a study entitled: "Factors affecting the abundance of Aedes taeniorhynchus and Aedes sollicitans." This grant, which was awarded to Dr. George O'Meara of the Florida Medical Entomology Laboratory with Douglas Carlson as a co-investigator, has used findings generated by CM 47,73, 93 and 122 as a basis for the research.

Indian River Impoundment Nos. 23 & 24 (both mainland impoundments) were chosen as the study sites because they represent different impoundment situations which periodically generate huge salt-marsh mosquito populations (i.e., both are unmanaged impoundments with one closed to the estuary while the other is open through a dike breach). Both egg and larval sampling techniques are attempting to provide information about the biology of these mosquitoes and in particular important relationships between them and various environmental factors (e.g., flooding stimuli, vegetation patterns, topography). A final report of this one year study will be complete within the next two months.

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Figure 1. Location of Impoundment 12

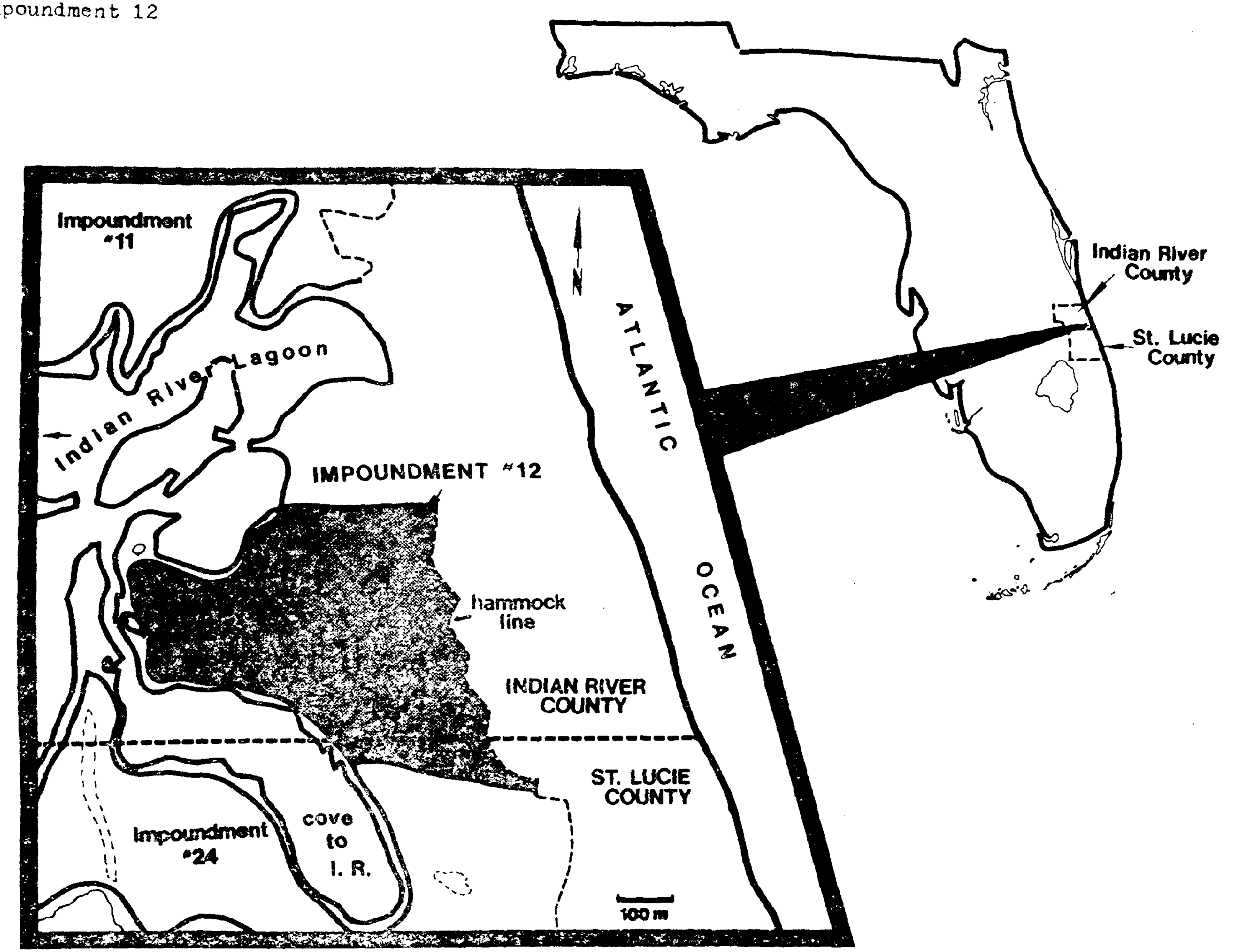


Figure 2. Map of mosquito sampling quadrats in Impoundment #12.

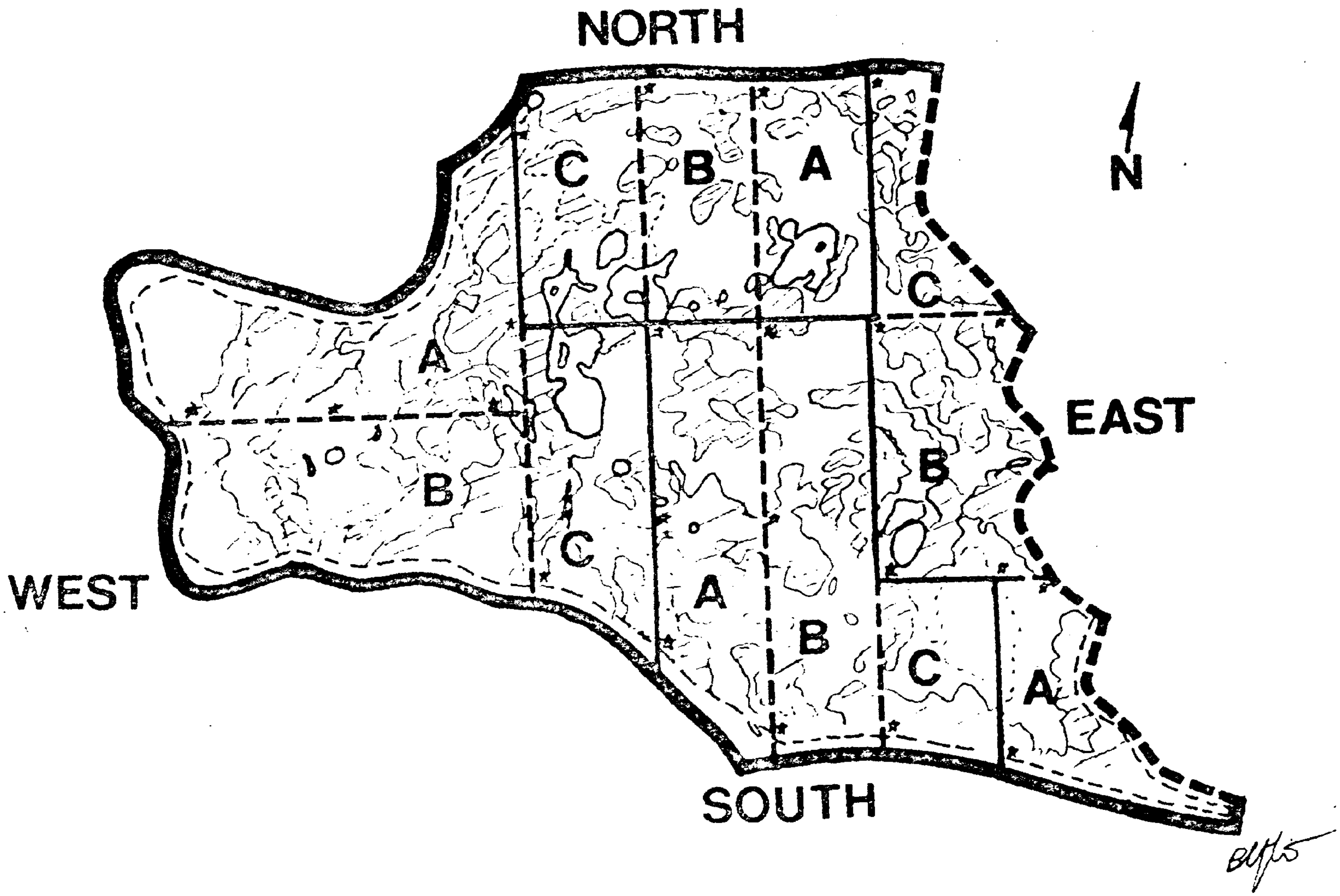


Figure 2b. Flapgate riser configuration used in Impoundment 12.

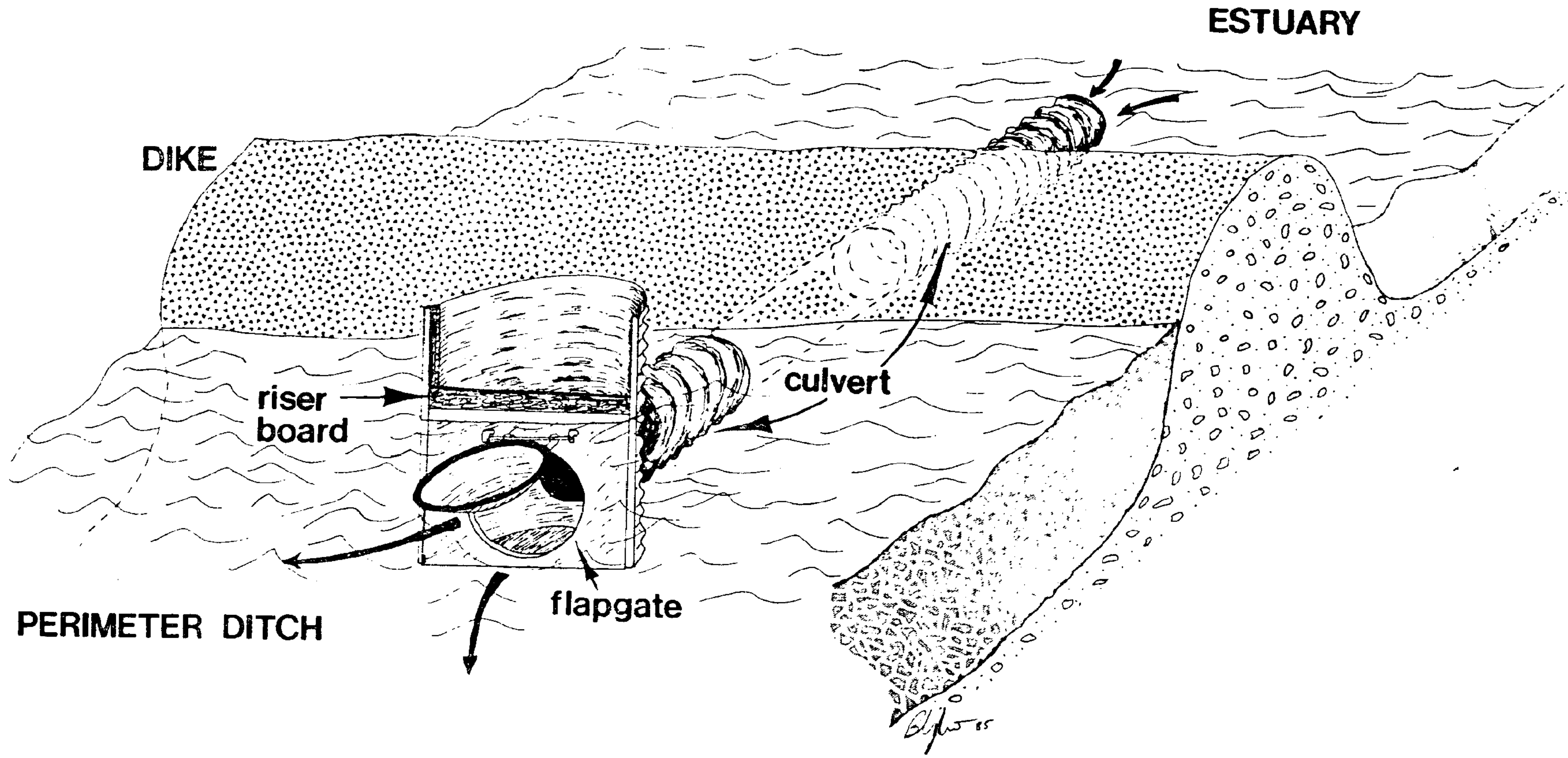
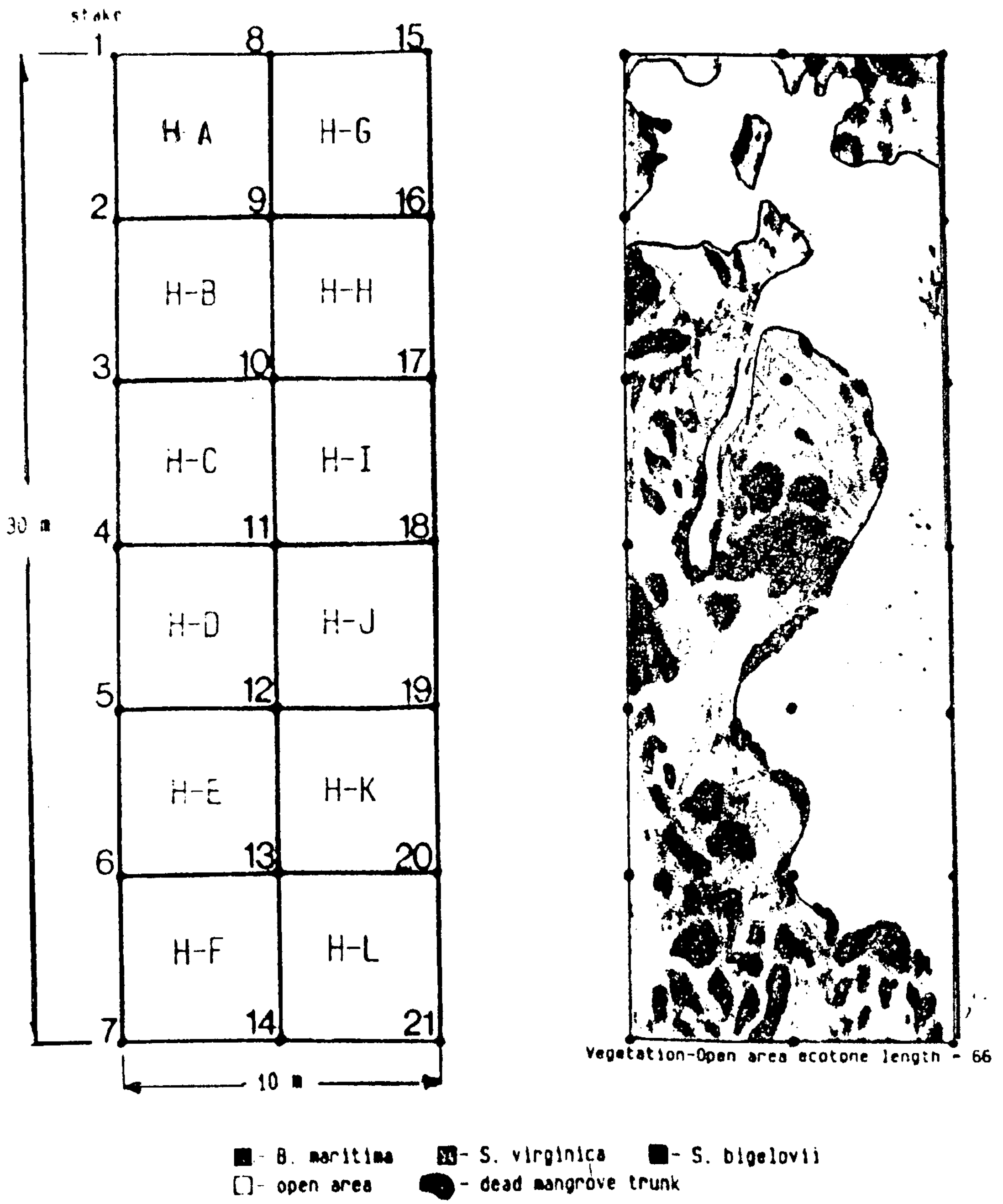
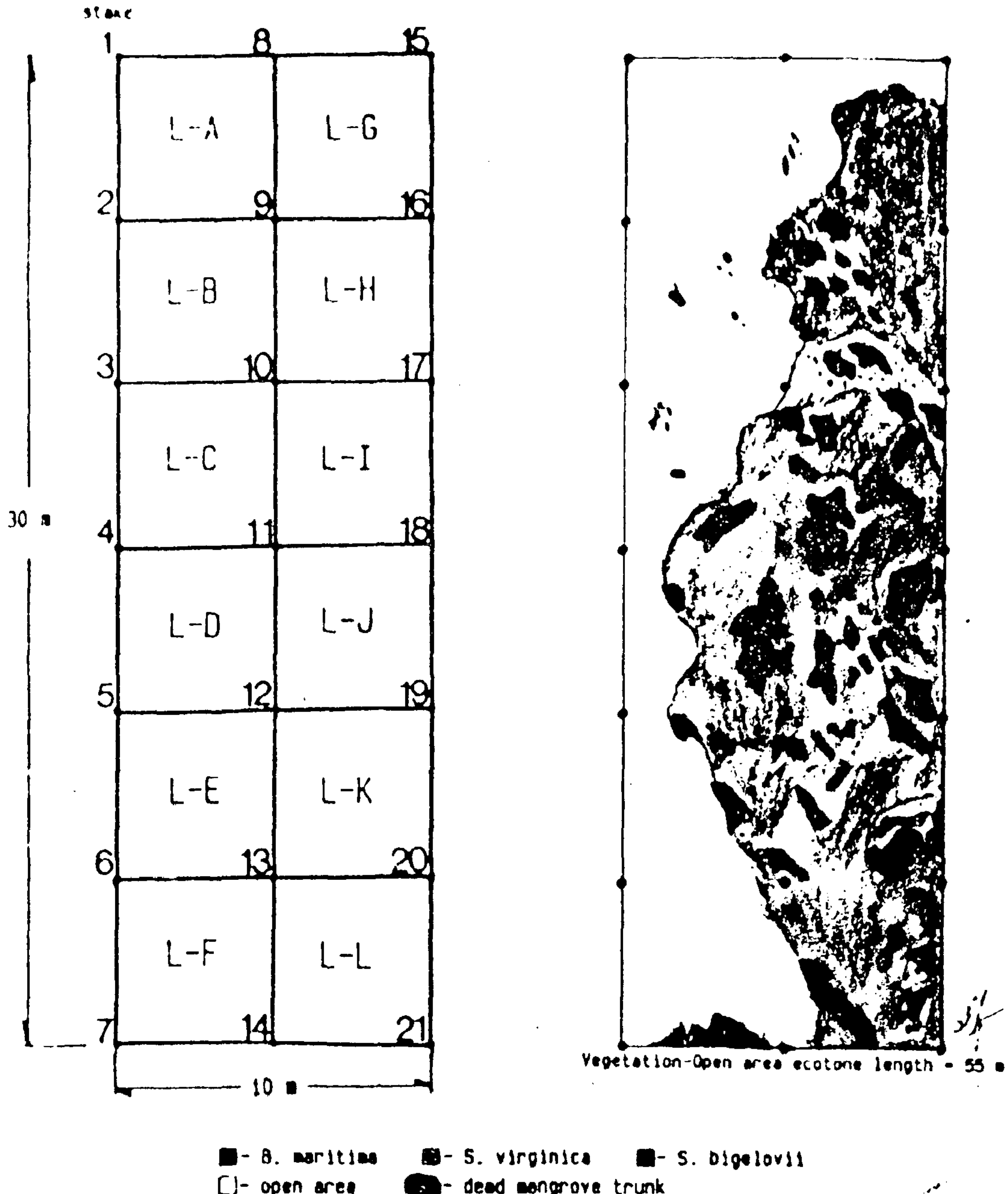


Figure 3. Vegetation at Hi-Breed site.



- dead vegetation in late Sept. 1986

Figure 4. Vegetation at Low-Breed site.



- dead vegetation in late Sept. 1986

Table 1. Mosquito production in Impoundment #12 (October 1, 1985 - September 30, 1986)

Date	North A	North B	North C	West A	West B	West C	South A	South B	South C	East A	East B	East C	Hatching stimulus
September 13, 1984 - Water management regime: impoundment open to estuary through both culverts.													
1985: December 7	66.6											351.4	
1986: January 1												78.0	
January 17												124.2	
February 9												15.6	
March 1												3.4	
March 27	4.3	2.3	7.5	25.7		20.8					1.9	117.4	
May 10												39.0	
May 16, 1986 - Water management regime: flapgates installed both culverts													
May 19, 1986 - Water management regime: riser boards installed both culverts													
May 23											1.2	635.8	
May 28,29, 1986 - Water management regime: estuarine pumping (9 hours)													
May 29										9.0			
June 4, 1986 - Water management regime: estuarine pumping (7 hours)													
Sept. 16, 1986 - Water management regime: Flapgates removed both culverts													

Broods are dated on day of hatching and expressed in X/dip.

R= rainfall; T= tides; B= both; P= pumping

Table 2: Aedes mosquito production summary at Impoundment 12

		NORTH			WEST			SOUTH			EAST			
YEAR	DATE	A	B	C	A	B	C	A	B	C	A	B	C	#EVENTS/ STIMULUS
1982	MAY (OPEN-1)	1 (90.7)	2 (2.0)	2 (2.6)	2 (93.5)	-	-	-	-	-	-	1 (19.1)	1 (34.5)	3 B
	JUNE (OPEN-1)	1 (1.4)	3 (1.8)	3 (3.3)	3 (14.6)	1 (3.6)	1 (0.2)	-	-	-	-	3 (13.7)	3 (77.2)	10 B
	JULY (OPEN-1)	-	-	-	-	-	-	-	-	-	-	-	-	-
	AUGUST (OPEN-1)	-	1 (2.0)	-	2 (38.2)	2 (4.2)	-	-	-	-	-	1 (5.4)	-	4 B
	SEPT (OPEN-1)	-	1 (15.5)	1 (138.6)	1 (28.6)	-	-	-	-	-	-	-	1 (116.5)	3 T
	OCT (OPEN-1)	-	-	-	-	-	-	-	-	-	-	-	-	-

		NORTH			WEST			SOUTH			EAST			
YEAR	DATE	A	B	C	A	B	C	A	B	C	A	B	C	#EVENTS/ STIMULUS
1983	MAY (OPEN-1)	-	-	-	-	-	-	-	-	-	-	-	-	-
	JUNE (OPEN-1)	1 (39.8)	1 (90.6)	1 (71.8)	1 (7.3)	-	-	-	-	-	-	-	3 (133.2)	3 B
	JULY (FLAPGATE-1)	-	1 (36.8)	1 (1.8)	-	-	-	-	-	-	-	-	-	1 R
	AUGUST (FLAPGATE-1)	-	1 (1.6)	-	-	-	-	-	-	-	-	-	1 (74.2)	2 R
	SEPT (FLAPGATE-2)	-	-	-	-	-	-	-	-	-	-	-	1 (2.1)	1 T
	OCT (FLAPGATE-2)	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 2: Aedes mosquito production summary at Impoundment 12

		NORTH			WEST			SOUTH			EAST			
YEAR	DATE	A	B	C	A	B	C	A	B	C	A	B	C	#EVENTS/ STIMULUS
1984	MAY (OPEN-2)	1 (1.0)	1 (0.3)	1 (0.2)	1 (0.5)	-	-	-	-	-	-	1 (1.6)	1 (2.8)	1 A
	JUNE (A-FLAPGATE) (B-CLOSED)	1 (2.2)	1 (54.7)	2 (1.0)	2 (11.4)	1 (0.1)	1 (0.1)	-	1 (0.2)	-	-	1 (128.2)	1 (162.3)	2 B
	JULY (A-FLAPGATE) (B-CLOSED)	-	-	-	1 (0.3)	-	-	-	-	-	-	-	-	1 A
	AUG (A-FLAPGATE) (B-CLOSED)	1 (2.0)	1 (9.1)	1 (6.2)	2 (3.5)	1 (0.2)	-	-	-	-	-	1 (12.1)	2 (166.1)	2 B
	SEPT (A-FLAPGATE) (B-CLOSED)	1 (4.9)	1 (72.1)	1 (119.5)	-	-	-	-	-	1 (0.1)	-	1 (0.1)	1 (527.8)	1 B
	OCT (OPEN-2)	-	1 (0.1)	-	-	-	-	-	-	-	-	-	1 (0.5)	1 A

		NORTH			WEST			SOUTH			EAST			
YEAR	DATE	A	B	C	A	B	C	A	B	C	A	B	C	#EVENTS/ STIMULUS
1985	MAY (OPEN-2)	-	-	1 (4.8)	2 (37.7)	-	-	-	-	-	-	3 (24.1)	4 (443.5)	4 B
	JUNE (OPEN-1)	-	1 (11.4)	1 (1.3)	-	-	-	-	-	-	-	-	1 (3.4)	2 A
	JULY (OPEN-2)	2 (23.4)	3 (16.1)	2 (93.7)	2 (133.2)	-	-	-	-	-	-	2 (243.2)	3 (89.1)	3 B
	AUG (OPEN-2)	2 (80.1)	2 (162.8)	1 (0.2)	-	-	-	-	-	-	-	2 (180.2)	3 (214.0)	3 B
	SEPT (OPEN-2)	1 (0.6)	1 (8.0)	1 (2.6)	-	-	-	-	-	-	-	1 (1.8)	1 (5.8)	2 (B
	OCT (OPEN-2)	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 2: Aedes mosquito production summary at Impoundment 12

		NORTH			WEST			SOUTH			EAST			
YEAR	DATE	A	B	C	A	B	C	A	B	C	A	B	C	#EVENTS/ STIMULUS
1985	MAY (OPEN/PUMPED)	-	-	-	-	-	-	-	-	-	1 (9.0)	1 (1.2)	1 (635.8)	3 T,P
	JUNE (FLAPGATE-2)	-	-	-	-	-	-	-	-	-	-	-	-	-
	JULY (FLAPGATE-2)	-	-	-	-	-	-	-	-	-	-	-	-	-
	AUG (FLAPGATE-2)	-	-	-	-	-	-	-	-	-	-	-	-	-
	SEPT (FLAPGATE/OPEN)	-	-	-	-	-	-	-	-	-	-	-	-	-

Broods are expressed as number of occurences and X/dip

R= rainfall; T= tides; B= both; P= pumping

Table 3. FLOW METER DATA

DATE	TOTAL FLOW TIME	MAXIMUM FLOW RATE
	FLOOD TIDES	
APR 21	5 hr 50 min	0.9 m/sec
APR 22 (1)	8 hr 27 min	1.2 m/sec
APR 23	5 hr 31 min	1.0 m/sec
APR 29	7 hr 6 min	1.2 m/sec
	EBB TIDES	
APR 21	6 hr 12 min	1.0 m/sec
APR 22 (1)	4 hr 30 min	0.5 m/sec
APR 29	6 hr 24 min	1.2 m/sec
SEP 16 (CULVERT OPENING)	9 hr 00 min	>1.0 m/sec

DATE	FLOW DIRECTON	MAX. FLOW RATE W/O CULVERT TRAP	MAX. FLOW RATE W/ CULVERT TRAP
APR 23 (2)	FLOOD	1.1 m/sec	0.6 m/sec
APR 23	EBB	0.5 m/sec	0.3 m/sec
APR 23	FLOOD	1.2 m/sec	0.8 m/sec

1 culvert trap installed during portion of tide cycle

2 partial tide cycle

PROCEEDINGS OF THE TWELFTH ANNUAL CONFERENCE ON WETLANDS RESTORATION AND CREATION

May 16-17, 1985

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Editor

Hillsborough Community College
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SALT MARSH IMPOUNDMENT MANAGEMENT ON FLORIDA'S CENTRAL EAST COAST: REINTEGRATING ISOLATED HIGH MARSHES TO THE ESTUARY

Douglas B. Carlson
Indian River Mosquito Control District
P.O. Box 670
Vero Beach, Florida 32961-0670

R. Grant Gilmore
Harbor Branch Foundation, Inc.
RR 1, Box 196
Ft. Pierce, Florida 33450

Jorge R. Rey[1]
Florida Medical Entomology Laboratory
Institute of Food and Agricultural Sciences
University of Florida
200 9th Street SE
Vero Beach, Florida 32962

ABSTRACT

In Florida, management methods in salt marsh impoundments which benefit mosquito control, fish and wildlife resources, and water quality enhancement are encouraged. Therefore, to provide quantitative management information, the water management regime of (1) opening a 20.2 ha. southeast Florida impoundment to the adjacent estuary with culverts through the dike, then (2) passively retaining water with flapgate risers has been studied to determine the effects on marsh flooding, vegatation, fish, macrocrustaceans, zooplankton, water quality, and mosquitoes.

The common mosquito control schedule of closing culverts in the early spring, retaining water during the spring and summer, then reopening the marsh on the fall high tides appears basically compatible with the major periods of fish ingress and egress. Significant regrowth of high marsh vegetation has occurred after reopening the impoundment to the estuary. The impoundment plankton fauna appears similar to that of other shallow water systems in Florida with copepods being the numerically-dominant group. With the present water-control-structure configuration (i.e., two 45.7 cm diameter culverts), passive water retention with flapgate risers to 1.0 feet NGVD has, so far, not been permanently detrimental to existing vegetation, but large mosquito broods were produced from rainfall and tidal flooding. Supplemental pumping will be necessary to provide adequate "source reduction" mosquito control benefits.

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[1]Authorship sequence determined by alphabetical order.

INTRODUCTION

Salt-marsh impoundments in Florida's central east coast are high marshes which were surrounded by dikes in the 1950's and 1960's and which are artificially flooded by pumping water from the adjacent estuary or with artesian wells during the mosquito producing season (approximately May-October). The salt-marsh mosquitoes (Aedes taeniorhynchus (Wiedemann) and Ae. sollicitans (Walker) lay their eggs in moist substrates, but will not oviposit upon standing water; the eggs hatch when they are flooded by tidal waters or by rainfall. Impounding, therefore, prevents these species from ovipositing in what otherwise would be highly attractive sites. This "source reduction" technique is both effective and economical in reducing populations of these mosquitoes (Clements & Rogers, 1964, Provost, 1977).

When most Florida impoundments were constructed, they were managed primarily for mosquito control and in some locations for waterfowl enhancement. Since then, research has now shown that impounding can interrupt the marsh-estuary exchange of organisms and detritus and kill high marsh vegetation if excessively flooded for prolonged periods (Gilmore et al., 1982).

Now that the importance of the high marsh in the lagoon system is recognized, organizations responsible for wetlands resources are encouraging management of these habitats in ways that minimize deleterious effects to wildlife and water quality while controlling salt-marsh mosquitoes. The ultimate goal is to enhance conditions for the former, without compromising the effectiveness of the latter. However, until very recently, studies on the effects of different management strategies on salt marsh flora, fauna, and physical conditions have been almost non-existent. Thus, management plans for impounded marshes have had to be developed with litte concrete information on their possible results.

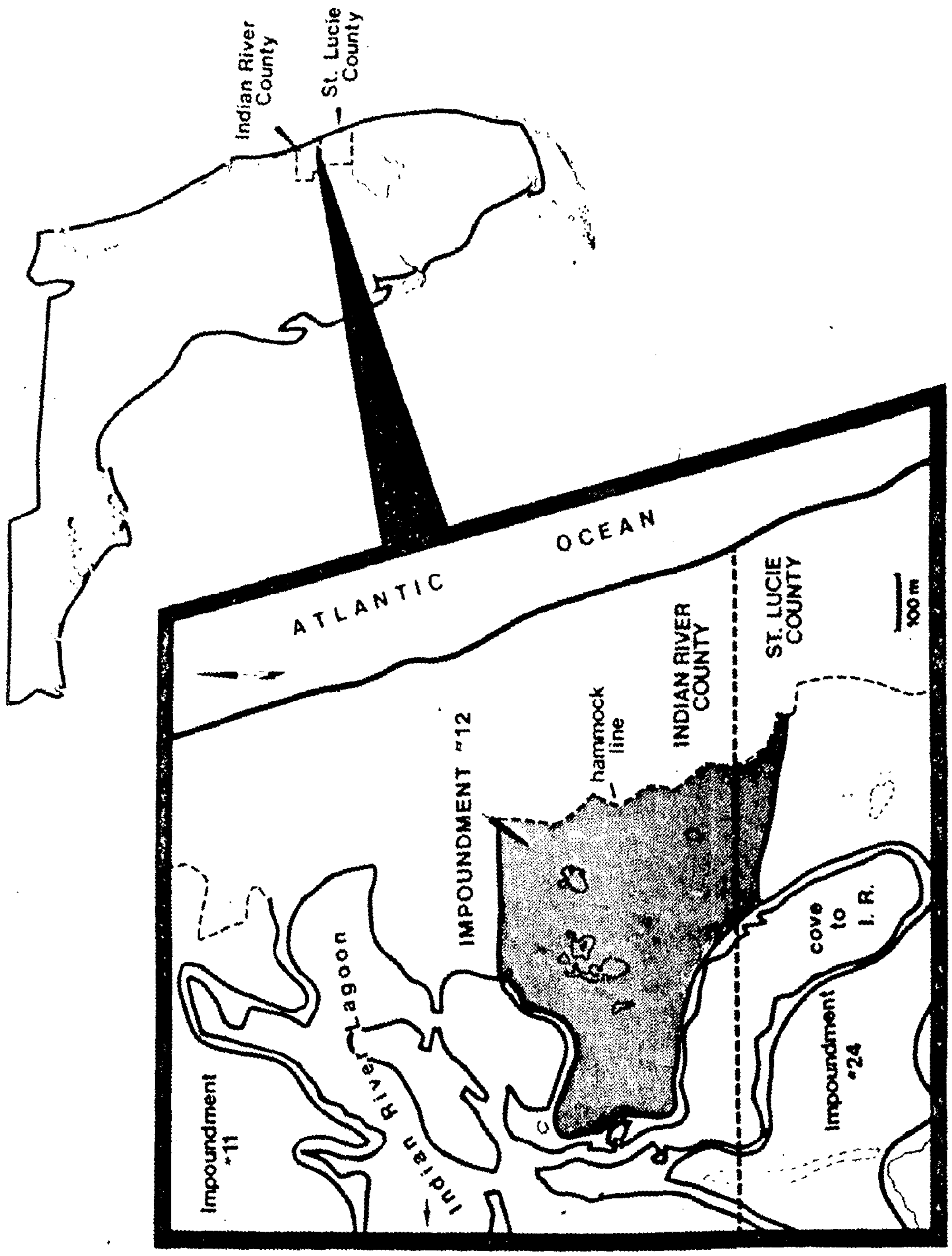
In an attempt to provide information that would be applicable to salt marsh impoundment management, a cooperative research project was started in 1982 between the Indian River Mosquito Control District, The Florida Medical Entomology Laboratory (University of Florida—IFAS), and the Harbor Branch Foundation, Inc. The project is investigating the effects on vegetation, fish and macrocrustaceans, zooplankton, mosquitoes, and water quality of reintegrating an isolated impounded high marsh to the Indian River lagoon system by first establishing connections through culverts through the dikes, and then passively retaining water with flap-gate risers.

SITE DESCRIPTION

The salt-marsh mosquito control impoundment used for this study is Indian River Impoundment #12 (Bidlingmayer & McCoy, 1978). This 20.2 ha. high marsh is located on the barrier island at the boundary between Indian River and St. Lucie counties. A shallow cove, which is part of the Indian River lagoon, lies southwest of the site (Fig. 1).

The impoundment was constructed in March, 1966, and was seasonally

Figure 1. Study site location.



flooded (approximately May-October) with water pumped from the Indian River lagoon until 1978 when pumping was discontinued at a property owner's insistence. From 1978 to 1982 water levels were allowed to fluctuate depending upon rainfall, evaporation, and percolation.

Most of the north and east sides of the marsh are bounded by an undiked upland edge, whereas the remainder of the impoundment is delimited by a man-made dike and perimeter ditch. The perimeter ditch ranges in width from one to eight meters, and is up to two meters deep, but many portions are filled with mud and organic debris. Well-defined drainage patterns are evident from the interior of the impoundment to the perimeter ditch. Numerous large depressions occur over the marsh surface, many of which retain water even during extremely dry periods thus forming permanent or semi-permanent ponds. Elevations of the marsh surface (excluding the perimeter ditch which is up to two meters deep) range from -0.35 to 1.80 feet (NGVD) (National Geodetic Vertical Datum) but the majority of the marsh ranges from 0.40 to 0.90 feet NGVD.

Presently, the most common plant species on the marsh are saltwort (Batis maritima L.), annual glasswort (Salicornia bigelovii Torr.), and perennial glassworth (S. virginica L.). Black mangroves (Avicennia germinans (L.)), red mangroves (Rhizophora mangle L.), and white mangroves (Laguncularia racemosa Gaertn.) are widely dispersed with the greatest regrowth along the perimeter ditch. Ruppia maritima L. (widgeongrass) is often very abundant in the permanent and semi-permanent ponds in the interior of the marsh.

An adjoining impoundment, St. Lucie County Impoundment #24, was used as a control for the zooplankton, vegetation, and water quality portions of this study. It is similar in nature to the experimental impoundment, but it has remained isolated from the Indian River throughout the study period.

METHODS

Scope

One of the major objectives of this study was to simultaneously obtain and integrate information on a variety of components of the marsh-lagoon system. To this end, there has been close cooperation during the design and implementation of the project between the three organizations involved. Nevertheless, the separate portions of this study have been carried in a semi-independent manner by the entities involved. The specific areas investigated are: mosquito production—Indian River Mosquito Control District; zooplankton, water quality, and vegetation—Florida Medical Entomology Laboratory; fish and macrocrustaceans—The Harbor Branch Foundation, Inc. In addition, a number of physical parameters have been monitored throughout the study by the three organizations.

Water Management

This study commenced in February, 1982, at which time a 45.7 cm (18 in.) culvert was opened to allow free exchange of water with the Indian River lagoon. In July, 1983, a flapgate riser was attached to the culvert and set at 1.0 feet NGVD (Fig. 2). The function of the riser is to trap rainfall and tidal waters within the marsh up to the set level, but allow any excess to spill over the riser and escape into the lagoon. In late September, 1983, an additional 45.7 cm culvert was placed to enhance marsh-lagoon interchange. In late January the flapgate risers were removed and unrestricted flow through the culverts was re-established.

Water Levels

Rain data were collected twice weekly with a tube range gauge. Bi-weekly maximum and minimum water levels at several locations within the marsh and in the Indian River were recorded with a greased staff-float apparatus.

Ichthyofauna and Macrocrustaceans

To obtain qualitative and quantitative information on the impoundment ichthyofauna, eight different types of sampling gear were used every two weeks over a 24 hour period to obtain a complete tidal and diel analysis. Different gear types were necessary to appropriately sample different microhabitats within the impoundment and because the organisms sampled are highly mobile and easily conditioned. The gear types included three static traps and five mobile traps. They were:

Static traps.

1. Heart trap—an aluminum frame adjustable aperture (to 35 mm), 3.2 mm ace weave mesh 0.62 X 0.78 m, 0.63 deep heart trap was used to capture fishes and macrocrustaceans moving through shallow areas extending from the marsh interior to the perimeter ditch such as tidal creeks or rivulets.

2. Culvert trap—this 1.52 m long, 44 cm diameter trap was specifically designed to trap organisms passing through the culvert.

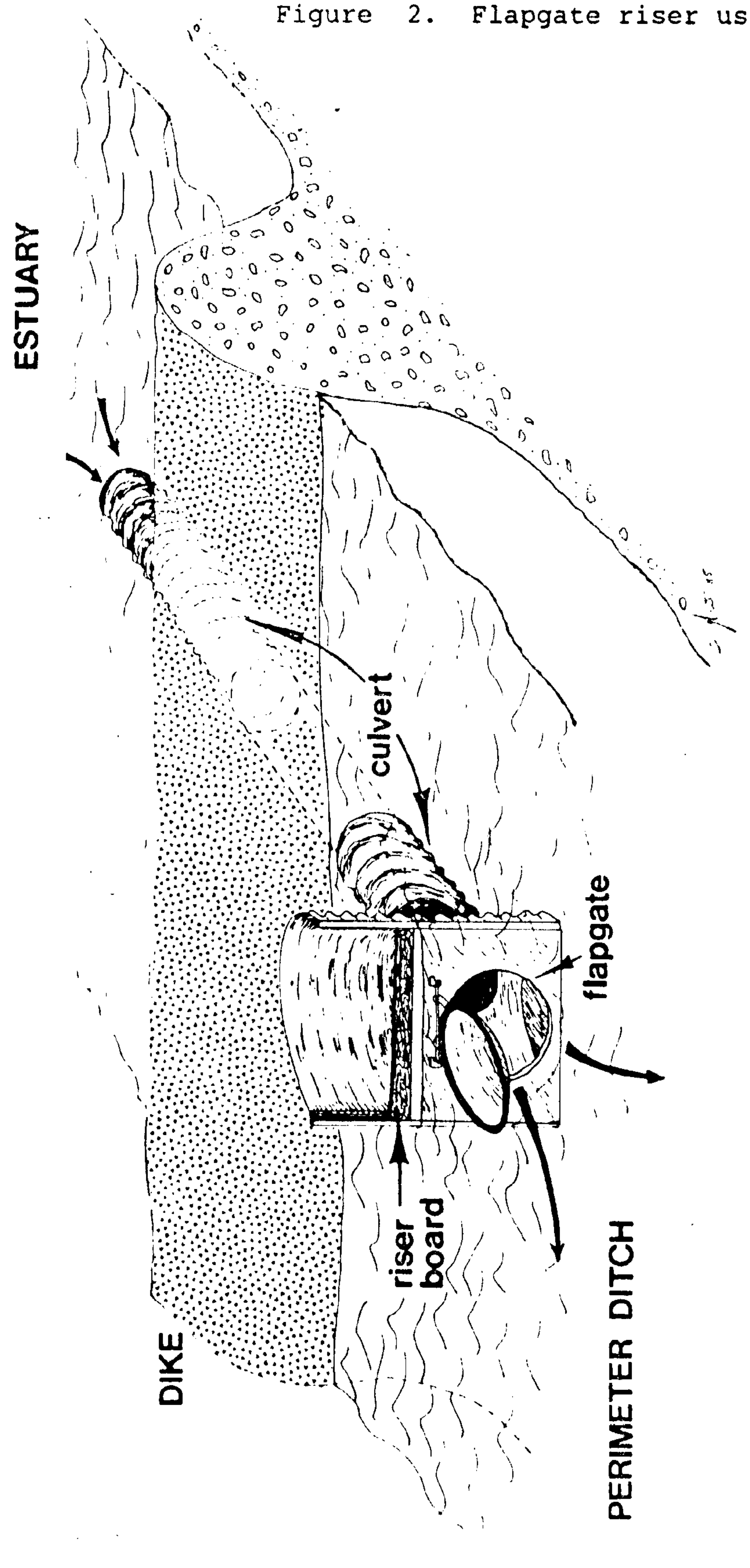
3. Culvert net—a 1.7 X 1.0 X 1.3 m, 3.2 mm mesh bait box net was modified to fish the water exiting the culvert.

Mobile traps.

1. Throw net—a 1.0 m^2 throw net was used to determine density and biomass samples in upper marsh ponds.

2. & 3. Seine nets—both 3.08 m, 3.2 mm and 15.2 m, 3.2 mm ace mesh bag seines were pulled over measured distances at various impoundment and adjacent cove locations.

Figure 2. Flapgate riser used in study.



4. Pull net—a 2 m X 5.65 m, 3.2 mm ace weave pull net was used to sample the perimeter ditch by pulling it over a measured distance.

5. Cast net—a 2.8 m radius, 2.5 mm mesh cast net was used to sample deep interior marsh locations.

Mosquitoes

The entire marsh surface was divided into 12 quadrats and at least twice weekly, mosquitoes were sought out in all quadrats. When immature mosquitoes (larvae or pupae) were found, mosquito broods (a group of immature mosquitoes in a sampling area which hatch and mature concurrently) were randomly sampled by taking 5-350 ml dips per quadrat. A mean size over the brood duration was determined.

Vegetation

Vegetation in the experimental and control impoundments was monitored along 1200 foot transects established across the marsh. Each transect was subdivided into 100 foot sections and five quadrat locations were established at random points within each section. At each location, the percent cover by each species was measured at quarterly intervals using a half-meter-square portable grid. The growth and survival of mangroves at the experimental and control impoundments were also monitored at quarterly intervals. One hundred seedlings were marked at each location and their growth and viability were recorded at each sampling.

In January, 1984, the Indian River Mosquito Control District conducted a visual survey of the vegetative cover of the experimental impoundment and recorded the qualitative frequency and abundance of the various species.

Zooplankton

Sampling for plankton in shallow waters is difficult because standard circular nets usually drag the bottom quickly clogging the meshes and contaminating the samples. Pump sampling in such habitats also has been generally ineffective because standard sieves become clogged before adequate samples can be collected and filtered.

We developed several techniques for sampling plankton in such marsh habitats that allowed us to obtain adequate sample sizes with a minimum of bottom contamination. These techniques included floating, rectangular nets, a large-volume filtering apparatus for pump samples, and hand nets. A total of 603 samples were taken at 4 stations, using these methods.

Water Quality

Twelve water quality sampling stations were established at strategic locations within the experimental and control impoundments, and in the Indian River. Sampling was started on September 25, 1984, and is being conducted on a 24-hour cycle at bi-weekly intervals. During each sampling, the following variables are measured and recorded at each site: dissolved oxygen, pH, water temperature, and salinity. A water sample is also collected at each site and taken back to the laboratory for further analysis. In the laboratory, nutrient analyses are carried out using a Technicon II Autoanalyzer system, and dissolved solids and tannin-lignin determinations with a Myron-L 512T3 DS meter, and a HACH TA-3 Test Kit, respectively. Results of the water quality sampling and analyses are still too preliminary to yield meaningful conclusions although some interesting patterns and differences between sites are already beginning to emerge.

RESULTS

Field work for this study is still under way; below we report on some of our preliminary findings and their possible management implications. A comprehensive report of our results will be produced upon completion of the project.

Marsh Water Level

Seasonal tidal effects played the greates role in setting the marsh water levels, with rainfall playing a smaller, but significant role. During both years the fall increase in water levels caused corresponding fluctuations within the marsh. Total coverage of the marsh usually occurred in early September, and persisted for several months. Water level measurements in the impoundment and also in the lagoon indicate that a standing water head was maintained within the marsh; that is, marsh water levels exceeded lagoon levels, and daily fluctuations outside the impoundment were usually greater than those inside.

Since the general marsh countour consists of gradual increase in elevations from the perimeter ditch (apprxoimately 0.40 ft. NGVD) to the upland edge (approximately 0.90 ft. NGVD) water levels below 0.45 feet NGVD generally flood only the perimeter ditch. However, rainfall can form isolated pockets of water away from the ditch which are not detected by the water level recorders (pers. obs.). Water levels of 0.60 feet NGVD flood as much of the western half of the impoundment and a flooding level of 0.90 feet NGVD or greater inundate the marsh to the eastern edge.

Ichthyofauna and Macrocrustaceans

1. General collection information. Marsh fish research originally began at the Impoundment #12 study site in January, 1979, when the impoundment was not open to the estuary nor managed for mosquito control. The fish fauna was compared to the fauna of another impoundment (Impoundment #23, St. Lucie County) which was open to tidal influence through a single culvert. The open impoundment (#23) was found to possess a far richer ichthyofauna (i.e., at least 30 additional species, Gilmore et al., 1982). Subsequent to this initial study, we demonstrated that when the closed impoundment site (#12) was reopened to tidal influence, considerable faunal changes occured with a major increase in species richness, i.e.,

from 12 to 45 species of macrocrustaceans and fishes.

Over 2,006 collections made from February, 1982, to April, 1985, in Impoundment #12 and two additional study sites have captured 465,310 individuals (449.5 kg—wet weight) of macrocrustaceans and fish representing 103 species (Table 1). Only 21 of these species, 41,215 individuals (7.3 kg), were crustaceans, contributing only 9 percent and 2 percent of the total number and weight of organisms collected, respectively. Therefore, the 82 fish species collected make up 91 percent of the total numerical catch and 98 percent of the sample weight, demonstrating the major contribution of the ichthyofauna to the marsh faunal biomass. It should be noted that the major marsh macrocrustaceans missed by these gear types are the burrowing crabs, *Uca* spp and *Cardisoma guanhumi* which add considerable biomass if sampled.

Fourteen fish species (totalling 95% of the total catch) are marsh residents which can reproduce within the marsh. Of the 89 transient species encountered, 74 are considered ephemeral migrators. Fourteen transients that depend on the marsh for a portion of their life cycle were collected. Twenty of the transient species captured are of commercial or sport fishery value and all of these spawn in open estuarine, neritic, or pelagic habitats.

2. Microhabitat faunal comparisons. For comparison purposes, the impoundment habitat was classified into (1) the lower marsh (=perimeter ditch) with the rest of the marsh being defined (2) upper marsh. The resident and transient fauna was more speciose in the lower versus upper marsh. The resident fauna was richer than the transient fauna on the upper marsh. More species of residents and transients occur outside the impoundment than on the upper marsh.

The transient fauna is richer than the resident fauna in the lower marsh from July to late November with this trend reversing from March to early July. Typically the largest catch of transient species took place in the culvert trap as migration into or out of the marsh required passage through this water control structure. Major transient species were recruited around adult spawning seasons. Primary immigration into the impoundment occurred with periods of sea level rise (May-June, August-October). Although some emigration occurred in June, most emigration of transient species takes place during the late fall and winter months as sea levels fall.

Mosquitoes

Mosquito sampling demonstrated that explosive, synchronous mosquito production triggered by rainfall and tidal flooding is possible in revegetating impoundments. The vast majority of mosquito broods (65 out of 75) were triggered by rainfall in the spring and summer, with as many as 1,444 larvae collected in one 350 ml dip. Mosquito production differed between some sampling quadrats and occurred at elevations ranging from 0.25-0.90 feet NGVD. Mosquito production during the first two years of study ranged from highs of 17 broods (with a mean brood size of 65.9

Table 1. Fish and macrocrustaceans collected from three impounded marsh sites (including Impoundment No. 12) from February 1982 to May 1985. Species are ranked by numerical abundance. Also given are weight (g) and specific relative occurrence (i.e., number of occurrences out of 2,006 samples taken). The numbers in parentheses indicate the percentage of total number or weight represented by the specific species.

Common Name	Species	Total Number	Total Weight	Specific Relative Occurrence
Sheepshead minnow	Cyprinodon variegatus	188480 (40.51)	129579.22 (28.83)	33.10%
Mosquitofish	Gambusia affinis	141237 (30.35)	24539.99 (5.46)	43.27%
Sailfin molly	Poecilia latipinna	63642 (13.68)	41760.42 (9.29)	36.24%
Grass shrimp	Palaemonetes spp	38566 (8.29)	4818.27 (1.07)	39.63%
Striped mullet	Mugil cephalus	5451 (1.17)	120929.49 (26.90)	23.53%
Ladyfish	Elops saurus	5238 (1.13)	9418.07 (2.10)	15.80%
Snook	Centropomus undecimalis	4752 (1.08)	13918.96 (3.11)	16.00%
White mullet	Mugil curema	2665 (0.57)	36427.69 (8.10)	12.91%
Marsh killifish	Fundulus confluentus	2499 (0.54)	2796.00 (0.62)	10.47%
Blue Crab	Callinectes sapidus	1364 (0.29)	25668.89 (6.00)	13.00%
Inland silverside	Menidia beryllina	1253 (0.27)	890.54 (0.20)	2.39%
Shrimp	Penaeus spp	1247 (0.27)	2439.89 (0.54)	13.75%
Irish pompano	Diapterus auratus	1054 (0.23)	1684.36 (0.38)	8.90%
Rainwater killifish	Lucania parva	951 (0.20%)	287.60 (0.06)	3.29%
Yellowfin mojarra	Gerres cinereus	740 (0.16)	650.71 (0.14)	6.68%
Tidewater mojarra	Eucinostomus harengulus	721 (0.15)	862.58 (0.16)	3.90%
Bay anchovy	Anchoa mitchilli	707 (0.15)	1711.91 (0.38)	2.29%
Silverside	Menidia spp	393 (0.08)	159.13 (0.04)	3.49%
Spot	Leiostomus xanthurus	383 (0.08)	721.80 (0.16)	2.24%
Silver jenny	Eucinostomus gula	350 (0.08)	1345.22 (0.30)	0.65%
Tarpon	Megalops atlanticus	343 (0.07)	6283.00 (1.40)	2.79%
Tidewater silverside	Menidia peninsulae	333 (0.07)	273.27 (0.06)	1.35%
Gulf killifish	Fundulus grandis	325 (0.07)	756.80 (0.17)	3.49%
Fat sleeper	Dormitator maculatus	321 (0.07)	2203.85 (0.49)	6.53%
Clown goby	Microgobius gulosus	258 (0.06)	46.12 (0.01)	1.45%
Code goby	Gobiosoma robustum	248 (0.05)	40.58 (0.01)	1.94%
Mojarras	Eucinostomus spp	233 (0.05)	17.88 (0.00)	1.60%
Pinfish	Lagodon rhomboides	212 (0.05)	4457.03 (0.99)	1.30%
Lined sole	Achirus lineatus	184 (0.04)	70.84 (0.02)	2.96%

Common Name	Species	Total Number	Total Weight	Specific Relative Occurrence
Black drum	*Pogonias cromis*	172 (0.04)	77.81 (0.02)	0.85%
Menhaden	*Brevoortia spp*	160 (0.03)	42.35 (0.01)	1.20%
Croaker	*Micropogonias undulatus*	79 (0.02)	96.01 (0.02)	1.20%
Killifishes	*Fundulus spp*	77 (0.02)	5.41 (0.00)	1.30%
Gray snapper	*Lutjanus griseus*	73 (0.02)	4228.52 (0.94)	2.69%
Gulf pipefish	*Syngnathus scovelli*	68 (0.01)	14.87 (0.00)	1.50%
Frillfin goby	*Bathygobius soporator*	47 (0.01)	126.74 (0.03)	1.84%
Sheepshead	*Archosargus probatocephalus*	39 (0.01)	2746.01 (0.61)	1.25%
Mangrove crab	*Aratus pisonii*	38 (0.01)	13.76 (0.00)	1.50%
Lyre goby	*Evorthodus lyricus*	33 (0.01)	90.05 (0.02)	0.55%
Sailors choice	*Haemulon parrai*	33 (0.01)	149.46 (0.03)	0.40%
Great barracuda	*Sphyraena barracuda*	31 (0.01)	169.33 (0.04)	1.30%
67 additional species were collected		310 (<0.01)	7004.75 (<0.02)	-
Total		465310	449525.18	

larvae/dip) in an east quadrat and 15 broods (with a mean brood size of 34.1) in a west quadrat to 0 broods in the three south quadrats. Of the mosquitoes collected, 82 percent were Aedes taeniorhynchus with Ae. sollicitans comprising 16 percent of the total sample.

Trapping of rainfall and tides with flapgate risers aided in eliminating oviposition sites but still allowed mosquito production in some marsh locations. Tidal flooding permitted larvivorous fish access to mosquito larvae, but these fish were unable to provide adequate control benefits to eliminate larviciding (Carlson & Vigliano, 1985).

Vegetation

Considerable revegetation by B. maritima, S. bigelovii, and S. virginica has occurred since the marsh was opened to the Indian River (Fig. 3). All three species of mangroves are growing well in the closed impoundment (control—Impoundment #24) (Fig. 4); in fact, to a much greater extent than in the experimental impoundment (#12). Considerable mortality of seedlings was evident in the open impoundment. Results of the transect survey show small changes in percent cover by other plant species during the first year of the study.

Zooplankton

As expected, copepods were the numerically-dominant group of organisms collected in the plankton samples. On a coarse scale, the plankton fauna of these marshes appear to be similar to that of other shallow-water systems in Florida except for a somewhat greater representation of primarily-benthic species, specially harpacticoid copepods, in the impoundment samples.

Preliminary analysis of the diversity and abundance data indicate that increased site isolation correlated with lower plankton diversity and higher individual abundances.

DISCUSSION

On Florida's central east coast, many impoundments have lacked tidal connection since they were constructed. However, concern over the possible deleterious effects of this marsh-lagoon isolation has recently resulted in an increased emphasis on developing multipurpose management strategies for these coastal impoundments. The creation of the Technical Subcommittee on Managed Salt Marshes, a subcommittee of the Governor's Working Group on Mosquito Control, is an example of this renewed emphasis on wise management of these valuable resources. The Technical Subcommittee, which was formed in 1983 to serve as a forum to integrate the numerous special management interests in impoundments, consists of 13 representatives from: (1) governmental agencies responsible for wetlands resources, (2) research institutions involved in salt marsh wetlands research, and (3) mosquito control agencies. It is responsible for reviewing the technical aspects of impoundment management plans, and of serving as an information gathering and dissemination source on the subject.

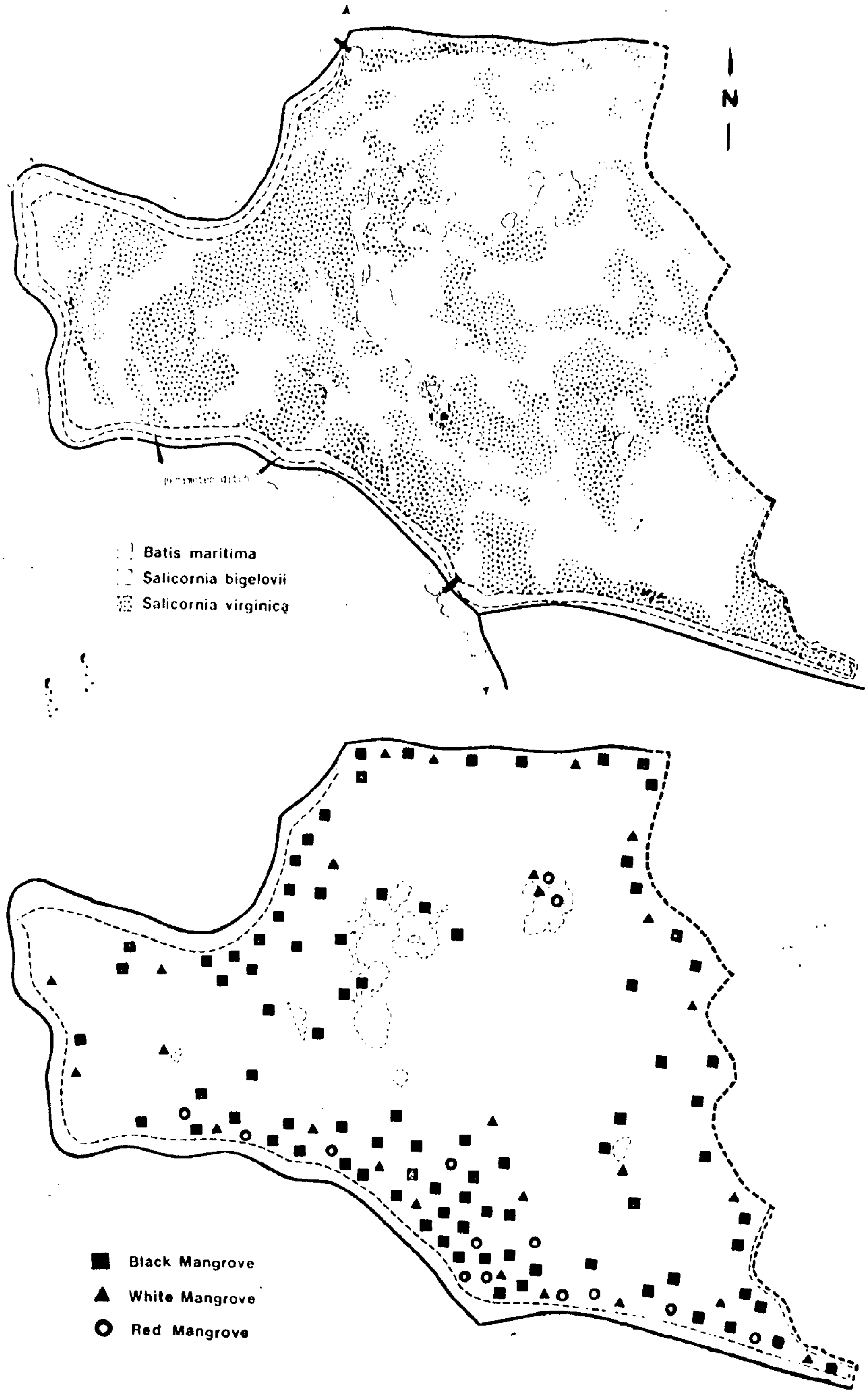


Figure 3. Approximate occurrence and location of major marsh vegetation (January 1984).

SLC #24: MANGROVE GROWTH

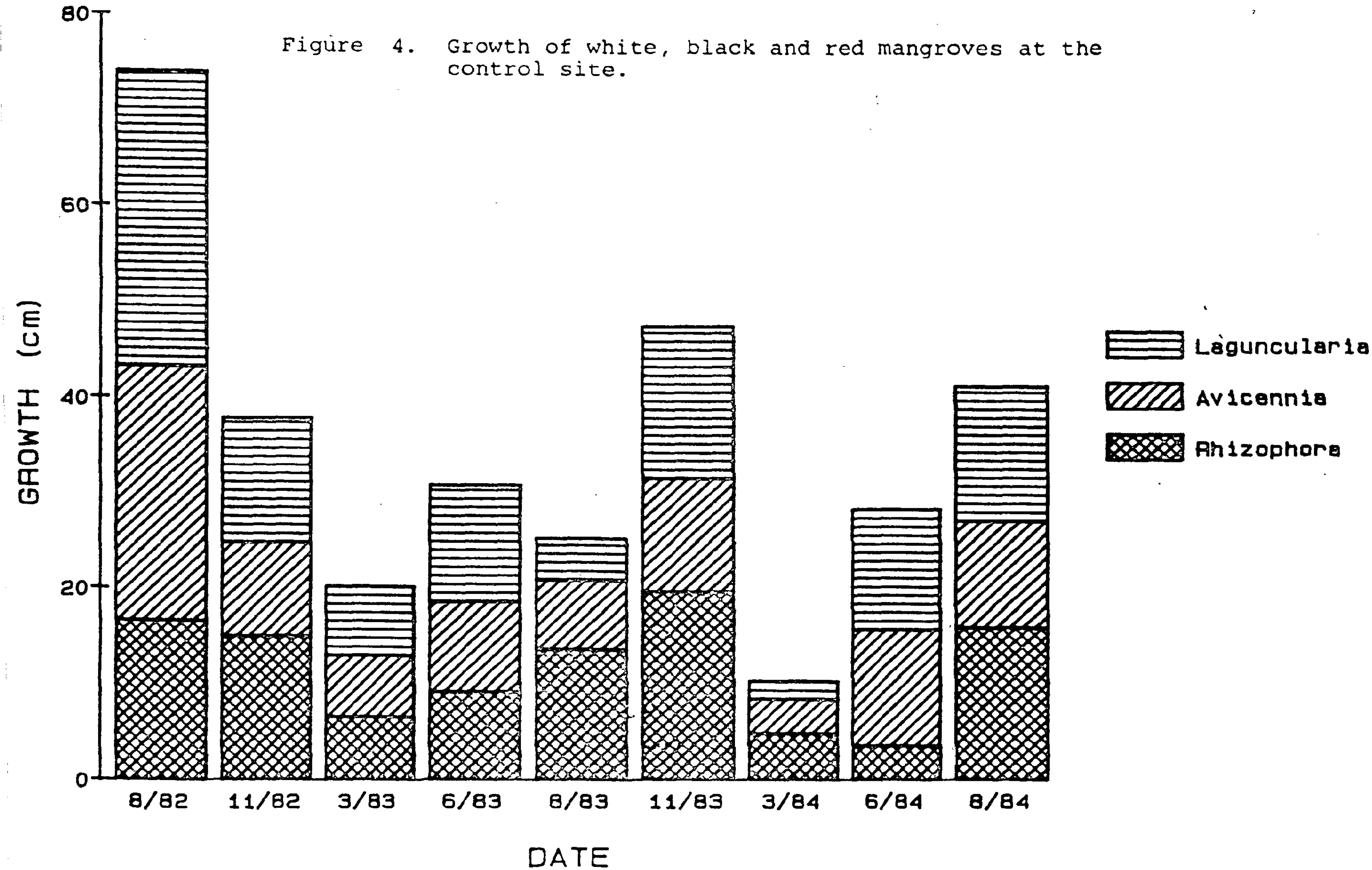


Figure 4. Growth of white, black and red mangroves at the control site.

Historical Effects of Impounding Salt Marshes

In central and south Florida, unimpounded marshes are generally vegetated with Batis, Salicornia, and black mangroves. In the late 1950's, Harrington and Harrington (1961) reported that 16 species of fish regularly use these high marshes. Unimpounded marshes also have been reported to produce large, synchronous mosquito broods which are hatched from rainfall and/or high tides (Harrington & Harrington, 1961). Impounding has been shown to cause significant mortality of marsh vegetation, and often results in the replacement of the typical Batis-Salicornia marsh with almost monospecific stands of red mangroves. A significant reduction of fish species diversity after impounding (16 to 5) has been demonstrated (Harrington & Harrington, 1982), but Gilmore et al. (1982) have shown that as many as 12 species of fish can regularly be found in isolated, unpumped impoundments regardless of the harsh environmental conditions of high salinities and low dissolved oxygen levels often occurring there.

Year-round or seasonal flooding can adequately control salt-marsh mosquitoes (Clements & Rogers, 1964). Also, if flooding is not excessive, vegetation can persist while controlling mosquitoes (Provost, 1974). Impounding also has been reported to change marshes barren of waterfowl to habitats very attractive for ducks and large wading birds (Provost, 1959).

Management Implications of Past and Current Research

The present study, although still in progress, has already produced important information that will be valuable when devising management strategies for salt marsh impoundments. This and other studies are showing that it may be possible to implement management methods which provide mosquito control benefits while minimizing many of the adverse effects usually associated with salt marsh impoundments and allowing the marshes to provide many of the benefits that they naturally produce.

Data from this study demonstrate that the normal mosquito control schedule of closing the impoundment in the early spring, retaining pumped estuarine water, rainfall and tidal waters within the impoundment, then reopening the marsh on the fall high tides with culverts placed through the dike is basically compatible with the major periods of fish ingress and egress. Both resident and transient fish species can use the culvert to pass between the marsh and the lagoon.

The vegetation data is encouraging. Although in 1979 the experimental impoundment was devoid of vegetation from past excessive flooding (Gilmore et al., 1982), it has experienced significant regrowth of the typical high marsh vegetation. The greater growth of all species of mangroves in the control cell (Fig. 4) is at first puzzling. Given the fact that the vegetation in most isolated impoundments consists of almost monospecific stands of red mangroves, one would expect that only this species would show greater growth in the control cell. It appears, however, that infrequent events, such as high rainfall, storms, and very high tides, may play a significant role in this phenomenon (Rey, in prep.).

With the present water-control-structure configuration (two 45.7 cm diameter culverts for a 20.2 ha impoundment), retaining water with flap-gate risers to the minimum elevation necessary for adequate mosquito control has, so far, not been permanently detrimental to succulent halophytic vegetation development. However, without the capabilities of augmenting the water levels established by rain waters and tidal intrusions by pumping lagoon water during the spring and summer months, unacceptably high numbers of mosquitoes were periodically produced in the experimental marsh. In another Indian River impoundment, Clements and Rogers (1964) showed that such supplemental pumping can provide adequate mosquito control benefits. This study has demonstrated that larvivorous fish are not able to control these synchronous mosquito broods even when they had access to the mosquito larvae. Fish gut analysis demonstrated that mosquito larvae were an insignificant part of the diet of marsh fish.

Research and experience are showing that many of the original functions of high marshes can be preserved while still maintaining multipurpose management, if the proper techniques are utilized. However, much work remains to be done to identify and "fine-tune" management strategies, and to determine appropriate variations when attempting to cope with different situations and/or management goals. Some goals may be attainable through generalized schemes that are compatible with a variety of objectives, while others may require very specific and idiosyncratic approaches. At the moment, the limitations to reintegrating these isolated high marshes are proving to be more political than scientific.

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Developing and Implementing Impoundment Management Methods Benefiting Mosquito Control, Fish and Wildlife: A Two Year Progress Report about the Technical Subcommittee on Mosquito Impoundments[1]

DOUGLAS B. CARLSON[2]

Indian River Mosquito Control District
P.O. Box 670
Vero Beach, FL 32961-0670

and

JOSEPH D. CARROLL, JR.[3]
U.S. Fish and Wildlife Service
P.O. Box 2676
Vero Beach, FL 32961-2676

ABSTRACT

The Technical Subcommittee on Mosquito Impoundments, a subcommittee of the Governor's Working Group on Mosquito Control, was formed in 1983 to serve as a forum to mediate the broad range of special management interests in salt marsh impoundments. It is helping to bring the latest research to the attention of the regulatory agencies thereby allowing these findings to be quickly incorporated into current management practices.

Technical Subcommittee guidelines suggest that impoundment management plans be written with the mutual objectives of mosquito control, fish and wildlife resources and water quality enhancement. Research is demonstrating that a rotational impoundment management (RIM) plan consisting of closing the marsh in the early spring, artifically flooding during the spring and summer, then opening culverts on the early fall high tides can allow for these multipurpose management objectives. Although further research and streamlining of the review and permitting process is necessary, other perhaps more important roadblocks to plan implementation are proving to be political and legal rather than scientific.

INTRODUCTION

Formation of the Technical Subcommittee on Mosquito Impoundments

Over the past 30 years, salt marsh impoundments on the east-central coast of Florida have been managed for mosquito control, in some locations for waterfowl enhancement, but with less attention given to their estuarine fishery resources and water quality values. Organizations developing or reviewing impoundment management plans have had little concrete information on the effects of various water management methods on which to base their decisions.

The need for a forum to mediate the broad range of special management interests in impoundments was addressed in 1983 by the formation of the Technical Subcommittee on Mosquito Impoundments, a subcommittee of the Governor's Working Group on Mosquito Control. The development of responsible management practices requires a thorough understanding of the local salt marsh ecosystem. East-central Florida salt marshes are no exception.

Central east coast Florida marshes

Tidal fluctuations determine the extent of coastal salt marshes. In Maine, annual tidal variations are masked by large daily tidal changes which reach over 18 feet. In contrast, the mean daily tidal ranges in south Florida are small while seasonal tidal fluctuations are significant (Provost 1976). Along Florida's east coast, tidal influences are often greatly diminished within bays and lagoonal estuaries. When far removed from the influence of an inlet, wind-generated water movements can be much more important than lunar tides in these es-

[1]The contents of this paper, which was presented at the annual meeting of the Florida Anti-Mosquito Association (May 1985, Sarasota, Fla.), may not represent the views and opinions of all Technical Subcommittee members.

[2]Current Technical Subcommittee Chairman.

[3]Technical Subcommittee member.

tuaries (Provost 1973, Smith 1980).

In Florida the relative importance of seasonal as opposed to daily tide ranges gives rise to a distinction between low and high marsh. Low marsh is flooded by daily tidal changes while high marsh is flooded only by seasonally high tides or rainfall. Tidal conditions along the central east coast of Florida produce a much greater ratio of high marsh to low marsh. It is the high marsh which produces salt-marsh mosquitoes, and thus they are the marshes that require physical control measures (Provost 1977).

Salt-marsh mosquito control impoundments

Mosquito control impoundments are high salt marshes which were surrounded by dikes in the 1950's and 1960's after local mosquito control agencies with the Florida State Board of Health verified that the marsh produced the salt-marsh mosquitoes *Aedes taeniorhynchus* (Wiedemann) or *Ae. sollicitans* (Walker). These mosquitoes lay their eggs on the moist soil of the high marsh which later hatch when flooded by rainfall or tides.

Impoundments can be artificially flooded during the salt-marsh mosquito producing season (approximately May-October) with water pumped from the estuary or from artesian wells. This 'source reduction' technique, which denies gravid mosquitoes oviposition sites, effectively and economically reduces their populations (Clements and Rogers 1964, Provost 1977).

However, impounding has potential environmental liabilities including the interruption of the exchange of organisms and export of nutrients and detritus between the marsh and estuary. Commercially and recreationally important transient marsh fish including *Elops saurus* L. (ladyfish), *Centropomus undecimalis* (Bloch) (snook), and *Megalops atlanticus* Valenciennes (tarpon) have been shown to depend on the high marsh for a portion of their life cycle (Wade 1962). The isolation of high marshes with dikes interferes with the use of this habitat by these fish species. Excessive or prolonged flooding can stress or kill existing high marsh vegetation and in many instances diking and flooding has promoted dense revegetation by *Rhizophora mangle* L. (red mangrove) (Gilmore et al. 1982).

At present, relatively little undiked marsh exists along the entire length of the Indian River estuary. There are approximately 11,800 ha of impoundments between Volusia and Martin Counties on Florida's east coast. Of this total, approximately 6500 ha are located in the Merritt Island National Wildlife Refuge[5]. The remainder is mostly privately owned.

Technical Subcommittee directives

Now that research has identified the importance of the high marsh in the estuarine ecosystem, impoundment management goals are becoming multipurpose. As a result, the management of impoundments on Florida's east-central coast is a topic receiving increased attention, study and regulation.

The simple environmental solution to returning impounded marshes to a more natural condition by increasing marsh-estuary interchange advocated by some environmental groups has been to breach the dikes. However, this option was not acceptable to mosquito control interests because this would terminate physical control capabilities and result in the need for periodic insecticide applications. Therefore, the directives to the Technical Subcommittee by the Governor's Working Group on Mosquito Control were to develop management guidelines with the mutual objectives of mosquito control, fish, wildlife and water quality enhancement.

In developing multipurpose impoundment management methods while assuring input from numerous special interests groups, 15 representatives were appointed to the Subcommittee who are knowledgable in marsh management with a wide range of special interests (Table 1). The representatives were from: 1) governmental agencies responsible for wetlands resources, 2) research institutions involved in salt marsh research and 3) mosquito control agencies.

The Subcommittee is an information dissemination source for salt marsh impoundment management and has also been given the responsibility of reviewing technical aspects of impoundment management plans submitted to state (Florida Department of Environmental Regulation (DER) and federal (U.S. Army Corps of Engineers (COE)) permitting agencies.

While past research has documented both beneficial and detrimental effects of impounding on the high marsh ecosystem, current research is showing that adequate mosquito control and fish and wildlife enhancement are mutually compatible objectives through carefully designed management methods[4]. Impoundment management is an applied science that should be based on scientific findings not merely on intuition. The Technical Subcommittee has drawn on past and current research in developing guidelines.

DISCUSSION

I. *Research providing salt marsh impoundment management information.*

Since 1956, salt marsh and impoundment research on Florida's east coast has demonstrated the resource value and mosquito production capability of these areas. The research has also shown the compatibility of management methods benefiting both mosquito control and fish and wildlife interests.

Table 1. Representation on Technical Subcommittee on Mosquito Impoundments.

Agencies responsible for wetlands resources.

Environmental Protection Agency, Atlanta, Ga.
Florida Department of Environmental Regulation, Tallahassee, Fla.
Florida Game and Fresh Water Fish Commission, Vero Beach, Fla. and Okeechobee, Fla.
Florida Department of Natural Resources, West Palm Beach, Fla.
National Marine Fisheries Service, Panama City Fla.
U.S. Fish and Wildlife Service, Vero Beach, Fla. and Titusville, Fla.

Research institutions.

Florida Medical Entomology Laboratory, Vero Beach, Fla.
Harbor Branch Foundation, Inc., Ft. Pierce, Fla.

Agencies responsible for mosquito control.

Brevard Mosquito Contorl District, Titusville, Fla.
Indian River Mosquito Control District, Vero Beach, Fla.
St. Lucie County Mosquito Control District, Ft. Pierce, Fla.
Office of Entomology, Florida Department of Health and Rehabilitative Services, Jacksonville, Fla.

Unimpounded high marsh. Harrington and Harrington (1961) reported the results of a 1956 preimpoundment ichthyofaunal study in "Jim's area" (Indian River Impoundment #12[5]) describing a typical high marsh. It was densely vegetated with *Batis maritima* L. (saltwort) and *Salicornia virginica* L. (glasswort) interspersed with *Avicennia germinans* (L.) (black mangrove). Concurrent with the Harrington's study, Haeger (1960) documented the huge mosquito producing potential in high marshes by reporting the migrating mosquitoes "started to depart in waves" from Impoundment #12.

In its undisturbed state, 16 fish species were using this marsh while feeding on a variety of organisms. Larvivorous marsh residents fed on mosquito larvae when they were superabundant. When mosquitoes were scarce they fed on other food sources primarily plant material and copepods.

Impounding with seasonal flooding. This marsh was impounded in March 1966. In September and October 1968 it was studied again. The purpose of this study was to determine the effects of impounding on marsh fishes. Almost all vegetation had died from overpumping. Only 5 fish species were collected which were feeding primarily on detritus and vegetation (Harrington and Harrington 1982).

In another Indian River impoundment (#25)[5], Clements and Rogers (1964) demonstrated that the flooding of salt marshes year round or seasonally from March through early September adequately controlled salt-marsh mosquito populations. They also showed that natural marsh flooding by rainfall or tides without additional pumping was inadequate for mosquito control purposes. Provost (1974) further demonstrated on a man-

[4]D. B. Carlson, R. G. Gilmore and J. Rey. 1984. Impoundment management. Unpublished report to the Florida Department of Enivronmental Regulation/Office of Coastal Zone Management (CM 47 & CM 73). 259 p.

[5]W. L. Bidlingmayer and E. D. McCoy. 1978. An inventory of the salt-marsh mosquito control impoundments in Florida. Unpublished report to Fish and Wildlife Service, U. S. Dept. of Interior. 103 p.

grove island in Brevard County, Florida, that when flooding levels were maintained low enough so that black mangrove pneumatophores or other high marsh vegetation was not inundated, the vegetation persisted while mosquitoes were controlled. Provost (1959) also reported that impounding marshes converted them from areas essentially barren of waterfowl into habitats especially attractive for ducks and large wading birds.

Impounding without artificial flooding. In 1978, the Indian River Mosquito Control District (IRMCD) ceased pumping estuarine water into Indian River Impoundment #12 at the insistence of a property owner. It remained isolated from the Indian River lagoon with water levels fluctuating only from rainfall, evaporation and percolation. In 1979, this area was the site of further marsh research which compared fish populations and habitat in open versus closed salt marsh impoundments (Gilmore et al. 1982). By then, the impoundment was essentially dewatered, receiving input solely from rainfall. Twelve fish species, including the larvivorous resident marsh fish collected by the Harringtons in earlier studies, were present but under stressed environmental conditions.

Impounding with connection to the estuary by culverts. From 1982 to the present, a cooperative study involving the IRMCD, R. G. Gilmore of the Harbor Branch Foundation, Inc., and J. R. Rey of the Florida Medical Entomology Laboratory (FMEL) has examined vegetation, fish, macrocrustaceans, zooplankton, mosquitoes and water chemistry in Impoundment #12 under the following management regime: 1) first opening to allow free exchange between the marsh and estuary through culverts, then 2) passively retaining water with flapgate risers.

This most recent research is indicating that the commonly accepted mosquito control management schedule of closing the impoundment in the early spring, retaining rainfall and tides during the spring and summer, then reopening the marsh on the fall high tides is basically compatible with major periods of transient fish ingress and egress. Fifty species of resident and transient fish have been shown to move through the 45.7 cm (18 in) culverts. Considerable revegetation by *B. maritima*, *S. virginica* L., *S. bigelovii* Torr. and *Laguncularia racemosa* (white mangrove), *R. mangle*, and *A. germinans* have occurred after the marsh was reconnected to the estuary. The study has confirmed the great mosquito producing capability of revegetating impoundments. It has shown that larvivorous fish are unable to control hatching larvae and has also demonstrated the failure of the technique of trapping rainfall and high tides to keep the marsh adequately flooded to completely preclude salt-marsh oviposition (Carlson and Vigliano 1985).

To summarize, research indicates that impoundments can result in the death of marsh plants from excessive or prolonged flooding, interrupt marsh-estuary interchange, reduce the number of fish species present and increase waterfowl usage. However, it also demonstrates that impoundment management practices can be developed which allow for mosquito control with seasonal lagoonal exchange that maintains marsh vegetation and benefits fish and wildlife. Over the past several years through cooperation between permitting agencies, developers and mosquito control agencies, a means has evolved to allow beneficial multipurpose management methods to become part of the broad array of impoundment management methods being used.

II. *Impoundment management plans*

Submittal. When a developer requests a dredge and fill permit for activities in an impoundment, or when a government agency (usually a mosquito control agency) desires to make structural modifications to an impoundment, permitting agencies encourage or often require long-term impoundment management changes as partial mitigation for loss of marsh habitat resulting from the project.

Guidelines. Technical Subcommittee directives to persons submitting management plans for review have been defined by the Governor's Working Group on Mosquito Control. They are that management plans should be written with the mutual objectives of mosquito control, fish and wildlife resources and water quality enhancement.

The most desirable environmental benefits appear to be those that attempt to mimic natural marsh functions through reestablishing marsh-estuary exchange and allowing for circulation within the impoundment. To enhance revegetation, it is suggested that water levels be maintained which will not cause damage to desirable plants.

The Technical Subcommittee has developed guidelines for organizations submitting management plans to permitting agencies[6]. The guidelines for management plan formulation and evaluation recommend incorporation of the latest research findings. Although the Technical Subcommittee is not a permitting organization, their comments are being used by state and federal permitting agencies in assessing the technical merit of submitted plans.

The Technical Subcommittee has compiled a list of technical considerations to be included in any management plan proposal. The plan should detail the impoundment's physical characteristics (including hydrology and topography), historical management methods, current management of nearby marshes, and biological data including past and present flora, current fauna, and considerations for endangered species[6].

Implementation. In light of research findings, the management method most favorably endorsed by the Subcommittee for use in saline barrier island impoundments has been a rotational impoundment management technique (RIM). This is accomplished by installing culverts with flapgate risers through impoundment dikes to reconnect the impounded marsh with the estuary on a seasonal basis. Culverts, the invert of which are set at -1.0 ft (-0.30 m) NGVD[7], are placed at strategic locations (e.g. historic natural tidal creeks) and are left open during the fall and winter, and then closed in early May. Flapgate riser height is set so that water levels exceeding that necessary for mosquito control can spill out into the estuary. During the mosquito producing season (approximately May to September) the impounded marsh is flooded by pumping water from the adjacent estuary. The culverts are opened in early September to allow the annual fall high tides to thoroughly penetrate and flood the marsh.

This is not to imply that this is the only acceptable method of impoundment management on the central east coast of Florida or the only method that will be considered, but to date this RIM method has received the most favorable acceptance for barrier island impoundments.

The St. Lucie County Mosquito Control District (SLCMCD) in conjunction with local developers and the Florida Department of Health and Rehabilitative Services (HRS) were the organizations to first enter into the management plan submittal process. Their plans for several Hutchinson Island impoundments helped pave the way for this complex permitting process to become a working reality. Since their early submittals and subsequent Subcommittee review, management plans have been or are being developed for impoundments in Brevard, Indian River, and Martin counties.

III. *Management plan issues*

The impoundment management plan submittal process has been like any new process involving numerous organizations protecting special interests. It has had its share of roadblocks and misunderstandings.

1. *Conceptual considerations*

Criticism that all plans have been alike

To date, all management plans submitted for review have been RIM plans on the barrier island or islands in the Indian River lagoon. Some Subcommittee members fear that until more effects of this management technique can be assessed, it may not be best to manage all impoundments identically. Others however, believe that research indications that RIM provides mosquito control and fish and wildlife benefits warrant moving ahead with this type of management technique.

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[6]Technical Subcommittee on Mosquito Impoundments. 1985. Information for permit applicants entering the impoundment management plan submittal process. 19 p.

[7]National Geodetic Vertical Datum, Vertical Control Data by the National Geodetic Survey, Sea-level Datum of 1929, U.S. Department of Commerce, National Oceanic and Atmospheric Administration.

It is likely that in the future, there will be requirements for innovative management methods designed to benefit specific goals. One example is preservation of the wood stork, *Mycteria americana,* which has been listed as an endangered species by the Department of the Interior[8]. The woodstork is a grope feeder requiring aggregations of fish and other aquatic food to satisfy its energy requirements (Kahl 1964). Therefore, plans for its recovery are likely to encourage or require slow drawdowns of water levels to concentrate food in impoundments near rookeries during the nesting season or when the young birds first fledge and leave the nest. Such management alternatives can probably best meet other wildlife and mosquito control needs if drawdowns are allowed to occur in late spring in isolated impoundments which are surrounded by flooded impoundments for several miles in all directions.

There also is interest in using impoundments as retention areas for secondarily treated wastewater (Carlson 1983a, Carlson 1983b). This management option would require careful study of the effects of introduced nutrients, the potential for freshwater mosquito problems in a salt marsh environment, and how different salinities could impact the salt marsh ecosystem.

Repair of dike breaches

Although it has generally been agreed that it is beneficial to the estuarine ecosystem to open up impoundments with water control structures, controversy was encountered when several Subcommittee members did not endorse sealing existing dike breaches and implementing a RIM. Breaches have generally occurred where the dike is exposed to wave action stress and erosion or where property owners have cut it.

Some environmental agencies opposing repairing dike breaks believe that insufficient information is available on the full effects of RIM plans. They also point out that fully open impoundments appear to revert to a more natural marsh condition more frequently than ones that are seasonally managed. In addition, it is maintained that it is unrealistic to try and maintain a dike which will continue to be stressed by natural occurrences.

Management plans have been submitted for several currently open impoundments which are several miles from densely populated areas. Because of the documented 20-30 mile flight range potential of salt-marsh mosquitoes (Provost 1952) and their mandate to control mosquitoes, mosquito control agencies have stated that without the ability to implement a RIM plan, they have no option but to larvicide on a need basis, invariably with follow-up adulticiding necessary. Chemical treatments, as opposed to physical mosquito control methods, are not preferred by mosquito control agencies because it is more costly and inefficient.

Several RIM plans, including the repair of a dike breach as part of the conditions, were submitted by the SLCMCD in conjunction with HRS. Subcommittee members' comments on this issue were mixed with no clear committee concensus as to whether the dike should be repaired and a RIM plan implemented. In the cases examined to date, the DER and COE have reviewed Technical Subcommittee comments and issued permits for the projects. However, implementation of the management plans is being held up by the Florida Department of Natural Resources (DNR) pending their permission to manage state-owned lands this way.

Necessary water control structures

How many water control sturctures are optimal for an impoundment is an important consideration. To date, the Subcommittee has operated on the premise that marsh-esturay exchange should be maximized but is this the best management strategy?

Historically, high marshes were usually surrounded by a berm at the mean high water level. Marsh flooding occurred only from rainfall or high tides (Provost 1967). Given the fact that high marshes were not continuously connected to the estuary, a proper impoundment management objective may not be to attempt to maximize water exchange. The installation of

[8]Federal Register 49:7332, Mar. 29, 1984.

numerous culverts so that water exchange and water level fluctuations exceed historical patterns may result in disruptive ecological changes.

Water level tracings are providing information showing how estuary water level changes are affecting impoundment water levels under different control structure configurations[4]. (R. G. Gilmore, pers. comm.). Further research is necessary to determine optimal estuary-marsh exchange requirements.

2. *Implementation considerations*

Property ownership

On Florida's east coast, many impoundments are privately owned with many under multiple ownership. Beginning in the early 1970's, some property owners insisted that mosquito control agencies cease pumping water onto their property. This has resulted in numerous unmanaged (non-artificially flooded) impoundments. For instance in Indian River County, 29 of the 30 impoundment systems (2800 acres), are privately owned. Presently, approximately 1000 acres are unmanaged at the property owners insistance.

Similar property ownership considerations are hindering the reconnection of impoundments to the esturay. Naturally, property owner consent is necessary to install impoundment structures on their land. Because an impoundment which is not connected to the estuary provides mitigation possibilities for a property owner, most developers are hesitant to allow implementation of a impoundment management plan on their property which may limit or hinder their options. Legal means to encourage a property owner to integrate his impounded marsh to the estuary now while still maintaining future development possibilities (e.g. mitigation banking) would be highly beneficial in meeting these objectives.

Confusion in the management plan submittal process

The process of submitting impoundment management plans to permitting agencies has been poorly defined. The Technical Subcommittee has attempted to coordinate its review of submitted plans with permitting agency timetables but a breakdown in communication oftentimes caused by personnel changes has led to misunderstandings and review delays. In addition, information requested by the Subcommittee and permitting agencies for plan review has not always been the same.

The management plan submittal and review process must be clearly defined for applicants and well coordinated between permitting agencies and the Technical Subcommittee in the near future. If this does not occur, developers may not be willing to enter into this costly, time consuming mitigation process for approval of dredge and fill activities in their privately owned wetlands. Instead they may decide it is not worth the time and money to pursue this option thus leaving impounded, isolated marshes in that relatively unproductive condition.

Monitoring

In order to implement an impoundment management plan, permitting agencies are frequently requiring monitoring of various parameters after the plan is in effect. This is intended to assess the plans effectiveness.

Proper scientifically acceptable monitoring which yields useful information requires carefully designed methodologies and thorough data analysis all of which are labor-intensive and expensive. When required, permitting agencies must devise a process where this information is properly reviewed and then used. We must avoid the situation where required monitoring of numerous convenient parameters is followed by ignoring and filing away of this costly information.

A related management consideration are requirements to maintain predetermined water quality levels in the impoundment. Care must be taken in establishing realistic and attainable standards. For example, natural salt marshes along the east coast of Florida do not continuously meet the established dissolved oxygen standard for Class III waters (Odum et al. 1982). They state that "In predominately marine waters, the concentration shall not average less than 5 parts per million in a 24 hour period and shall never be less than 4 ppm."[9] Forcing an agency to attempt to maintain such unrealistic criteria must be avoided. Water quality goals must be reasonable, if they do not meet present State Water Quality Standards.

Another important monitoring consideration is the lack of uniform scientifically accepted methods for mosquito surveillance. Through experience mosquito control agencies use various surveillance methods they have found works well for their particular situation. Subjective assessments frequently based on political considerations are sometimes unavoidable.

CONCLUSIONS

Research and experience are demonstrating that salt marsh impoundments can be reintegrated to the estuarine system while maintaining mosquito control and providing fish and wildlife benefits. The Technical Subcommittee on Mosquito Impoundments is serving an important function as a vehicle bridging between research and regulatory communities. This is allowing recent research findings to be quickly brought to the attention of persons managing salt marshes, then encouraging these findings to be incorporated into current management practices.

Also of importance, the Technical Subcommittee is aiding in the education of permitting agency personnel on the technical aspects of impoundment management. Although they are responsible for final plan approval, permitting agencies have been faced with rapid turnover of personnel and oftentimes poor coordination among those reviewing management plans within an agency. This has hindered reintegrating impounded marshes with the estuary.

Further research is necessary to determine management considerations such as what type, size, and number of water control strutures are optimal for an impoundment. However, in its two year existence, the Technical Subcommittee has made noteworthy strides in aiding in the development of impoundment management methods benefiting wide ranging interests. Presently, much information is available on which to base management decisions. The roadblocks to multipurpose management implementation are more political and legal rather than scientific. The impoundment management plan submittal process is still not thoroughly defined and inadequately coordinated between responsible organizations.

To facilitate reintegrating impoundments into the estuarine system while at the same time maintaining 'source reduction' capabilities, we recommend: 1) streamlining the management plan submittal and review process to make it straightforward, understandable to applicants, and coordinated among permitting agencies, 2) means to allow long-term, flexible implementation of approved management plans, 3) methods to allow and encourage a property owner to reconnect his impounded marsh to the estuary now without losing future mitigative options and 4) realistic, cost conscious management plan implementation requirements of applicants.

[9]Florida Administrative Code, Chapter 17-3.121-Water quality standards.

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D

Spectral Analysis of Fish, Zooplankton and Mosquito Data Collected in Impoundment 12.

by

Alan Curtis

Indian River Mosquito Control District

P.O. Box 670, Vero Beach, FL 32961-0670

Introduction

This portion of CM-122 was funded to provide rigorous statistical analyses of the data for 4 major aspects of marsh ecology studied at impoundment 12 over the past 4 years: fish/zooplankton utilization; vegetation growth; mosquito production; and water quality. The major goal of this statistical analysis was first, to describe more accurately periodic population trends and any interactions between fish, mosquitoes and zooplankton in the impounded marsh; and second to determine the impacts on the marsh ecology of differing impoundment management strategies. This particular statistical investigation was not intended to include or take precedence to the specific individual analyses conduced by the other contributing principal investigators. Its objective was to pursue statistical avenues that were some what unrelated to the individual studies, but were commonly shared by the projects entirety.

The data available for analysis varied widely in their completeness and detail: specifically, the fish data was the most comprehensive data set; zooplankton, because of the difficulties of identification and quantification, was detailed but did not yet provide an up to date data record; and mosquito population data presented relatively straightforward information requiring little additional confirmation of results.

We had further hoped to analyze the interrelationships of the 4 major areas of study. However, since the early stages of this work had not anticipated such an analysis of merged data, we realized this might be difficult because of dissimilarities among sampling protocols and schedules. Further difficulties were presented by the time lag in analysis of collected specimens--especially zooplankton; and by gaps in the data records in 1983..1984, between funding periods. And, in fact, after careful examination of the specific individual data collections it was determined that it was not possible to jointly correlate all the data sets. The specific data sets formed discrete groups that were generally non-overlapping in time and space, limiting the analytical options available for serial analysis. We were, however, able to conduct some preliminary analyses with the collective fish and zooplankton data.

For this impoundment analysis, we concentrated on the best available data while retaining the initial analytic design of using time series analysis to determine trends and periodicities in the data sets.

Analysis thus concentrated on Mr. Gilmore's fish data. These were most suited to analysis due to the experimental design and the data record length, which is of paramount important in time series analysis. It also represents an aspect of marsh ecology which impounding and flooding obviously impacts, but which has not been studied prior to this work at impoundment 12. We felt that concentration in this area would provide valuable information which would enhance management-related decisions which impact impoundment fisheries.

Fish collections are available for processing since 1982 but there is a 18 month gap in the data set after 12 months of continuous sampling. This disrupts the continuity of the data to an extent that only the 1984-1986 fish data could be used for time series analysis. This data, however, was sufficient to yield important information.

The brevity of the zooplankton data made it difficult to conduct accurate time series analysis of the data. There was only 9 months of classified plankton data available for random data processing. However, some limited conclusions could be gleaned from the data set.

The entirety of the mosquito data (1982-1986) was also analyzed. This analysis was restricted to the relationship between mosquitoes and time. The more detailed ecological evaluation of mosquitoes and their habitat was left to Mr. Carlson and Mr. O'Bryan in there attention to the subject.

Water quality and vegetation analysis was deferred to Dr. Reys' survey of the data collected. Both of these studies are continuing to provide information to be appraised at the completion of the study. Time series analysis of the current data would be premature in content.

Time Series

Spectral analysis has been used extensively in the modelling of biological systems (Kirk and Rust, 1982 and Curtis, 1986). These models rely on the identification of the various periodic components of a particular data set for the understanding of the overall system. Components fall into two basic categories; biotic and abiotic, with the biotic variables generally responding to the environmental stimulus of the abiotic input.

Differing periodicities in presence and abundance of fish results either from environmental perturbances or actual ichthyofauna periodicities. To describe these differences and identify the cyclic characteristics I have employed a method time series analysis known as spectral analysis.

As an introduction to this subject, a brief list of random data processing terms use in this paper is presented here, followed by a discussion of the reasons for preferring this mode of analysis for the type of data gathered at impoundment 12.

<u>Ensemble</u>. The collection of all time history records that have been produced form the fish or plankton sampling.

<u>Stationary data.</u> Given an ensemble of time history records (the fish or plankton collection from 1982-1986) , the average properties of the data for any specific time can easily be computed. When one or more of these averages varies with changes in time the data are considered to be nonstationary. If the averages remain constant with changing time then the data are said to be stationary.

<u>Fourier series.</u> The most common method used in time series analysis to detect periodic changes in time history records, Its use is based on the fact that with few exceptions periodic data can be expanded in a Fourier series composed of sines and cosines over the ensemble of data.

<u>Periodogram.</u> The graphic representation of a particular data history record evaluated over time using autocorrelation, crosscorrelations, Fourier transforms, or maximum entropy methods to determine periodic components within the data.

<u>Maximum entropy spectral analysis (MESA).</u> Basic to MESA is the assumption that the stationary time series being considered is the most random or least predictable. MESA is based on the idea of choosing the spectrum which corresponds to the most random time series whose autocorrelation function agrees with given values (Kirk <u>et</u> <u>al</u>. 1979).

<u>Filter coefficients.</u> Filter coefficients roughly correspond to the term "bandwidths" or "segment lengths" in Fourier analysis. This is basically the sensitivity of analysis over a given data ensemble. Analyses in either fourier analysis or MESA, are computed over various intervals of the data record to produce a frequency spectrum. The narrower the segment, the more random noise affects the spectrum. A wider segment produces a more smoothed response. The number of coefficients chosen in a particular analysis is dependent upon the time history length and type of data under consideration. The most useful analyses are

those in which the number of coefficients chosen produces pronounced peaks in the frequency spectrum with little background noise.

Time series analysis is used extensively in data analysis of long term biological studies such as the one conducted at impoundment 12. This analysis provides insight into the periodic components of a particular phenomenon, whether biotic or abiotic.

Traditionally, fourier transform analysis is used to determine cyclic trends in the data. This method of analysis converts the data ensemble into a series of sines and cosines from which periodic components are identified. Critical to accurate identification of spectral density (periodic fluctuation) is an ensemble of sufficient length to minimize the signal to noise ratio. If the record length is too short, any cyclic components will be masked by the variance noise. In biological interpretations, data record length is particulary crucial since there may be seasonal as well as short term breeding cycles that could easily be disguised by the random noise in a short data record.

Sufficient record length is determined by several criteria, the foremost is determining the shortest observable periodic change that is desired. This dictates the sampling frequency that must be employed during the study. Sampling must be conducted at twice per cycle of the highest frequency (shortest period) that can be resolved. This means that if you expect a periodic event to occur weekly, sampling must be conducted twice per week to detect and accurately describe this event. The frequency $f_n = 1/(2 \Delta t)$ is called the Nyquist frequency (Bendat & Piersol, 1971) and is the highest frequency that can be resolved with a sample interval of t. The situation is actually worse than it appears on the surface because if x(t) does have important harmonic components at frequencies greater than the Nyquist frequency, then these components will distort the spectrum values at lower frequencies. This is because the approximation cannot distinguish between the frequency f and the frequency $(1/\Delta t\text{-}f)$. This phenomenon is called aliasing and must be allowed for in experimental design.

The second important consideration in determining the ensemble length is the actual statistical variation inherent in the biological system under observation. If the variation is minimal and predictable then sampling duration may at times be limited to twice the longest periodicity, if we expect to see an annual cycle as with the fish then it will be necessary to sample for a minimum of 2 years to detect this frequency accurately if the variance is minimal. However, most biological systems are statistically noisy due to environmental perturbations and natural fluctuations. This generally dictates that studies with time series forecasting in mind must be several years in length.

The exception to the long data record length requirement is when Maximum Entropy Spectral Analysis (MESA) is used, in certain cases this method remains statistically accurate with a limited data history (Kirk *et al*. 1979).

Data Analysis Procedures

For each data set (fish species, zooplankton and water depth) traditional time series analysis was employed, which implements smoothing and detrending to estimate the power spectrum of the autocorrelation function. This removed all linear trends by least-squares-fit to the data and subtraction from the data to obtain a function with zero mean and a standard deviation of one. Then the spectral estimates were derived via the MESA method. The statistical result is series of entropy values (energy) at various predetermined frequencies. Frequencies selected ranged form the maximum (one year) to the minimum (two weeks) periodicity detected, evaluated in 2.50E-02 weekly intervals, which is the width of the integration window. The intensity or magnitude at these frequencies is a quantitative measure of the periodicity of the data set. For any given data record a number of frequencies will appear in the periodogram, some meaningful, others representing only random noise. To separate the significant energy from background noise Fisher's Periodogram Test was employed (Fisher 1929).

Crosscorrelations between the biotic parameters (fish and plankton) and water depth were examined in the typical manner. The data sets were first detrended to remove any linear increase or decrease during the course of the study. The actual crosscorrelations were conducted to determine the relationships between the biotic factors and water depth at various time lags.

RESULTS

Figures 1-3 graphically depicts the historical information concerning the fish collections at impoundment 12 from 1984-1986. Visual inspection strongly indicates periodic behavior with all three of the fish species. These graphs are 2 point moving averages of the actual data points, this removes some of the inherent variation in the data so that the overall trends may be visualized.

The first step in data processing of this type is examination of the autocorrelation function of the individual data sets. *Cyprinodon variegatus*, *Gambusia affinis* and *Poecilia latipinna* all exhibited significant 1 sampling period lags which rapidly decayed at increasing lags. This basically means that collections of fish today are strongly associated with the previous sample (2 weeks ago) and that the next sample (2 weeks from today) will be correlated with the current sample. This is a common situation with biological data, especially with resident species. Autocorrelation of the water depth data also indicated the same significant "nearest neighbor" dependence.

Crosscorrelations between the 3 resident fish species and water depth to were used to evaluate whether there was any potential association between these variables in the time domain. In other words, as water elevations change over time is there a measurable relationship with the fish or plankton changes. Cyprinodon variegatus and water depth (Fig. 5) indicated a significant negative association at the time lags between -3 and 3 sampling periods, with sampling period being every 2 weeks. This shows that as water depth increased the number of C. variegatus decreased. Apparently this is not an actual decrease in fish numbers but a decline in trapping efficiency. As the surface of the marsh increases, with increasing water levels the fish spread out over the expanded marsh, decreasing the density. Poecilia latipinna (Fig. 7) exhibited the same negative association with water depth, the abundance of fish was depressed as water levels increased. Gambusia affinis (Fig. 6) sharply contrasted the other 2 resident fish in that it was significantly positively associated with increasing water depth. This live bearing fish appears to immediately accept changes in the water levels to its benefit. It is readily collected in saltmarshes due to its behavioral nature near the surface of the water. Rapid reproduction facilitates G. affinis' ability to populate the increased habitat formed when water levels elevate.

Spectral analysis of the fish data set revealed a number of interesting results especially in the short term frequencies. Visual interpretation of the MESA periodograms is quite simple, the frequencies are converted to actual periodicities (Period= 1/frequency) which constitute the x axis, the y axis is the magnitude of the entropy values it is a unit of measure for that particular graph and is not statistically comparable to another ensemble. The peaks on the plots are areas of high spectral energy representing some cyclic event. The maximum entropy spectra of C. variegatus (Fig. 8) shows 2 significantly distinct peaks, the first is the long term cycle at approximately 40 weeks. This high energy spectra represents the annual cycle of this resident fish in impoundment 12. Additionally there is a short term peak cycling with a period of 5 weeks. Depending upon the number of filter coefficients used in the estimation of the MESA, this short term peak could vary ± 0.5 weeks. The initial hypothesis is that this peak is coincidental with either the moon phase or the monthly tidal cycle. Figure 11 the MESA plot for water depth, contains no spectral energy in the short term range, so the short term period of C. variegatus is not tidally induced. It is likely that this represents breeding cycle for this fish.

Gambusia affinis (Fig. 9) demonstrates a very similar spectra configuration to that of C. variegatus, with a annual cycle approximating 40 weeks. The short term energy for G. affinis is also in the 5 week range (5.8 weeks ± 0.5 weeks). There is also addition broad spectral energy between 10-15 weeks, this is more than likely a harmonic frequency of the shortest significant peak at 5.8 weeks. The harmonic frequency is further evidence that there is a short term (5.8 week) breeding cycle.

The third resident fish under investigation, Poecilia latipinna (Fig. 10) has a quite contrasting periodogram to those of the other resident fish. The two largest peaks are the short term period at 5.7 weeks and the slightly larger one at 10 weeks. The longer of these two is probably a harmonic of the shorter. The annual cycle is more compressed than any of the other fish and is slightly displaced from the 39 week period of C. variegatus and G. affinis to a period close to 50 weeks. A biological explanation for the striking difference in spectra energy between the short term periods (10 and 5.7 weeks) and the annual cycle is unsupported by the current data. Further knowledge about the biology of P. latipinna is necessary to form better conclusions concerning the importance of the various spectral peaks observed.

The spectral analysis of water depth (Fig. 11) proved to be quite intriguing. The only significant spectral energy occurs at 40 weeks (the annual periodicity). Although, water levels are considered to be tidally driven and tide changes occur daily with pronounced changes occurring twice per month with lunar phase progression. These elevation changes were not detected by this analysis for several reasons. Impoundment 12 is situated distant from ocean inlets which allow tidal exchange between the ocean and estuary. Water level fluctuations here are influenced more by wind driven stimuli than the more common oceanic tides, whose effect at impoundment 12 is dampened by distance. The epic wind effects are not sufficiently periodic to be statistically evident in a data record of this length. Comparing the fish data with the epic changes of water levels indicate that the only statistically predictable and significant periodicity is that of the annual cycle. This annual cycle or peak occurs during the fall in coastal southeastern Florida. The three most common resident fish C. variegatus, G. affinis and P. latipinna respond dramatically to this seasonal change in water elevation these fish exploit the seasonal tide as a habitat strategy for maximum utilization of the marsh. The increasing water levels bring with it additional food and increased surface area. The flooded marsh affords developing fish protection in the now aquatic vegetation inundated by the advancing water levels.

Zooplankton collections presented a more difficult statistical problem in that their ensemble was shorter than that of the fish. Figure 4 shows the smoothed graph of the collections over the first 9 months of the investigation. There is a strong peak in zooplankton collections during the summer months.

Unfortunately the fish and plankton could not be evaluated in concert due to the physical limitations of sample sorting and identification. Only the 1982-83 plankton data were available for statistical investigation. The plankton like the fish showed an annual periodicity, but unlike the fish or water depth data its' peak of spectral energy (Fig. 12) was much broader ranging from 40 - 20 weeks. This wide are of energy is probably due to the high variance associated with the plankton collections and the short data ensemble analyzed, which make accurate evaluation of the data difficult. There is also a short term periodicity at about 5.5 - 6 weeks, whose' biological explanation is yet forth coming.

Mosquito presence and abundance is extremely epic generated. The principle mosquito under investigation Aedes taeniorhynchus responds to both rainfall and tidal inundation as a hatching stimulus. Rainfall is a random variable fluctuating in amount and frequency and although there is a significant correlation between mosquito abundance and water depth at a 1 day lag (crosscorrelation) there is no periodic component in the presence or abundance of A. taeniorhynchus when evaluated by MESA.

This is not an unexpected finding that there exists no periodic component in the mosquito data. Periodic fluctuations in citrus mosquitoes was found to occur only when inundation by periodic flood irrigation occurred or when rainfall patterns demonstrated cyclic evidence (Curtis, 1986). At impoundment 12 neither of these requirements transpired. Rainfall over the period studied was truly a random non-periodic variable and water depth demonstrated only a seasonal periodicity.

Crosscorrelations between mosquito abundance and fish collections also proved to be insignificant. There is a general misconception that mosquito populations are controlled by the presence of fish. The data evaluated in this study demonstrates that there is not a negative association between mosquito abundance and fish abundance. Mosquito populations are extremely explosive and development times of this insect may be as short as 5 days during summer months. Resident fish probably can not compete in time with the rapidly metamorphosising mosquitoes. In fact the traditional mosquito fish G. affinis is a lower marsh resident where saltmarsh mosquitoes milieu is the upper marsh, whose narrow interface fluctuates with rainfall or tides.

CONCLUSIONS

It is obvious from the inspection of the power spectra of the fish data records that foremost, fish are most abundantly active on a seasonal basis. Short term abundance is probably related to breeding cycles. There is no statistical evidence that fish abundance is regulated by lunar cycles. At least at impoundment 12, lunar phase has no effect monthly on water depth changes. Water depth was found to be seasonally regulated with a single periodic component at approximately 40 weeks. It would seem imperative that fish habituating marshes be given access during this annual phenomenon.

Inspection of the entire data records for the three resident fish indicates that they have increased in abundance during the course of the study. This is probably directly related to the increase of the vegetation in the marsh, which provides not only food for the fish but also protection from predators.

Figures 1-3 display the entire data record for the 3 resident fish during the course of the statistical study (1984-1986). The 3 species each respond differently to the period of impoundment closure and subsequent flooding (by pumping). Gambusia affinis numerically increases where the other 2 indicate apparent decreases, in reality these declines are sampling artifacts, the fish are dispersing through out the habitat lessening the trapping efficiency. However, G. affinis is actually taking advantage of the increased surface area and water depth.

RECOMMENDATIONS

There are several events that could have greatly added to the completeness of this part of the study. The original scope of the project was well conceived and used appropriate experimental designs by the individual investigations (i.e. fish, plankton and mosquitoes).

However, if accurate forecasting models were to be constructed several different approaches should have been taken. The first and most difficult to implement is sampling frequency. The sensitivity of the model is directly related to experimental sampling design, with sampling every two weeks projections can only be expected to be reliable at twice that. So detecting short term changes can only be accomplished with more continual sampling. This would have been difficult to accomplish due to the physical constraints of the project, mainly man power. The sorting and identification of the samples collected was time consumptive upon the biological staff of each of the projects. Taxonomic and numerical processing of the plankton collections was so laborious that only the first year of the data was available for statistical evaluation. This in fact is the predominant reason that the fish and plankton data could not be jointly assessed. To accommodate this difficulty in future projects it is imperative that addition technical personal be provided to rapidly process the data parameters monitored.

Data analysis of this type of information should be conducted following completion of the project, when the bulk of the data has been sorted and the basic biological interpretations arrived at and not during the course of the investigation. Individual project analysis should be complete with general hypothesis and conclusions well established prior to a comprehensive time series analysis.

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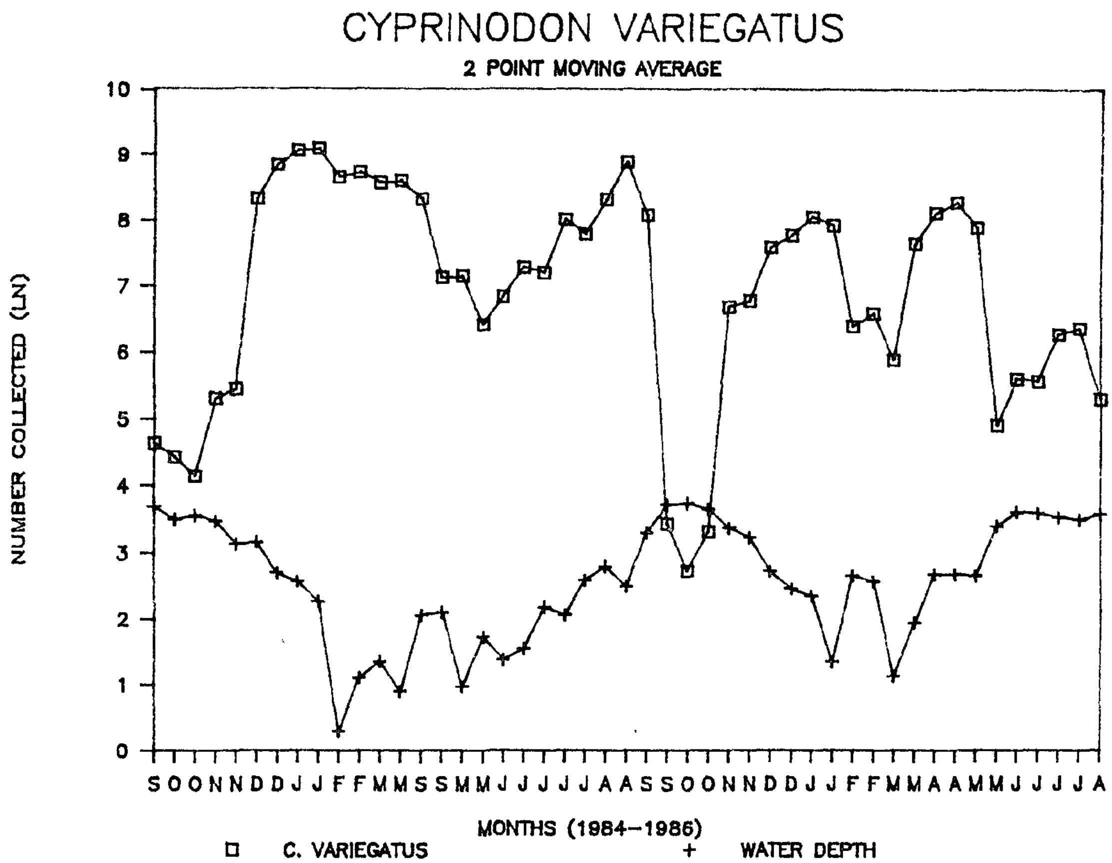
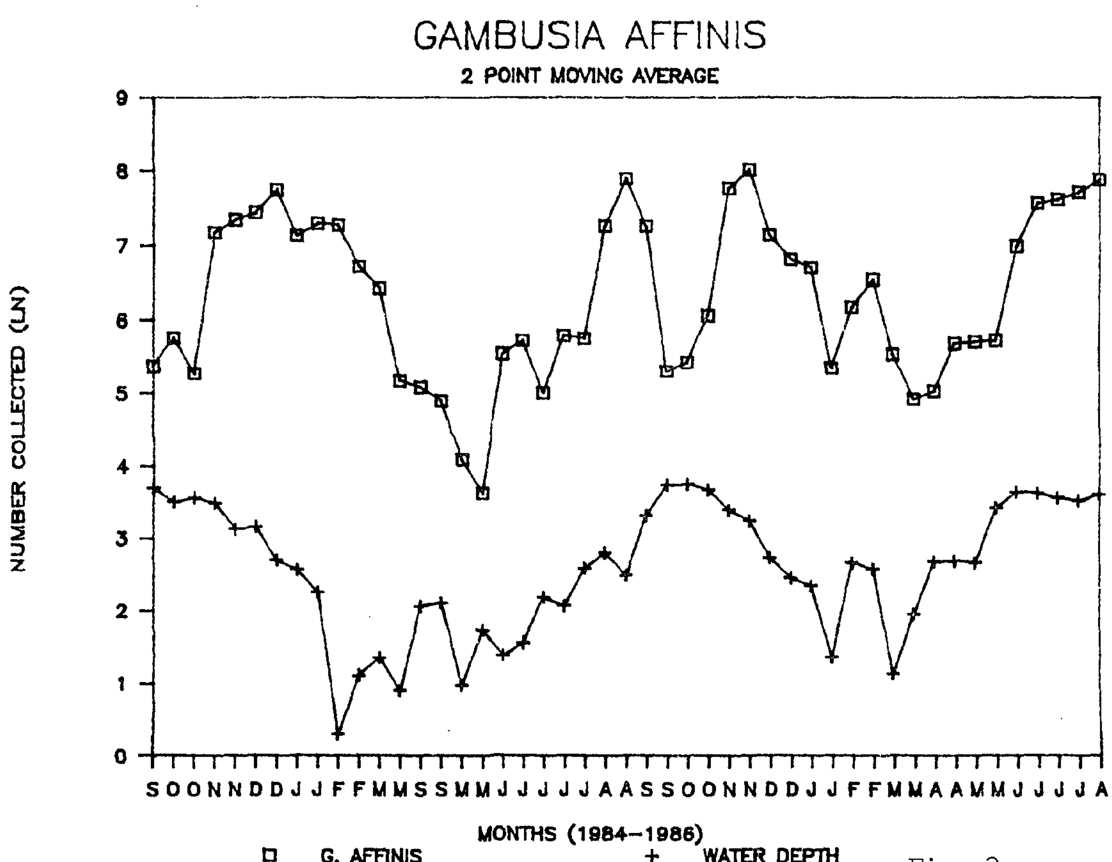
Kirk, B.L., Rust, B.K. & Van Winkle, W. (1979), Time Series Analysis by the Maximum Entropy Method. ORNL-5332. Oak Ridge National Laboratory, Oak Ridge, Tennessee, 218 pp.



CYPRINODON VARIEGATUS
2 POINT MOVING AVERAGE
NUMBER COLLECTED (LN)
0
1
2
3
4
5
6
7
8
9
10
S O O N N D D J J F F M M S S M M J J J J A A S S O O N N D D J J F F M M A A M M J J J J A
MONTHS (1984–1986)
C. VARIEGATUS
WATER DEPTH

Fig. 1



GAMBUSIA AFFINIS
2 POINT MOVING AVERAGE
NUMBER COLLECTED (LN)
0
1
2
3
4
5
6
7
8
9
S O O N N D D J J F F M M S S M M J J J J A A S S O O N N D D J J F F M M A A M M J J J J A
MONTHS (1984–1986)
G. AFFINIS
WATER DEPTH

Fig. 2

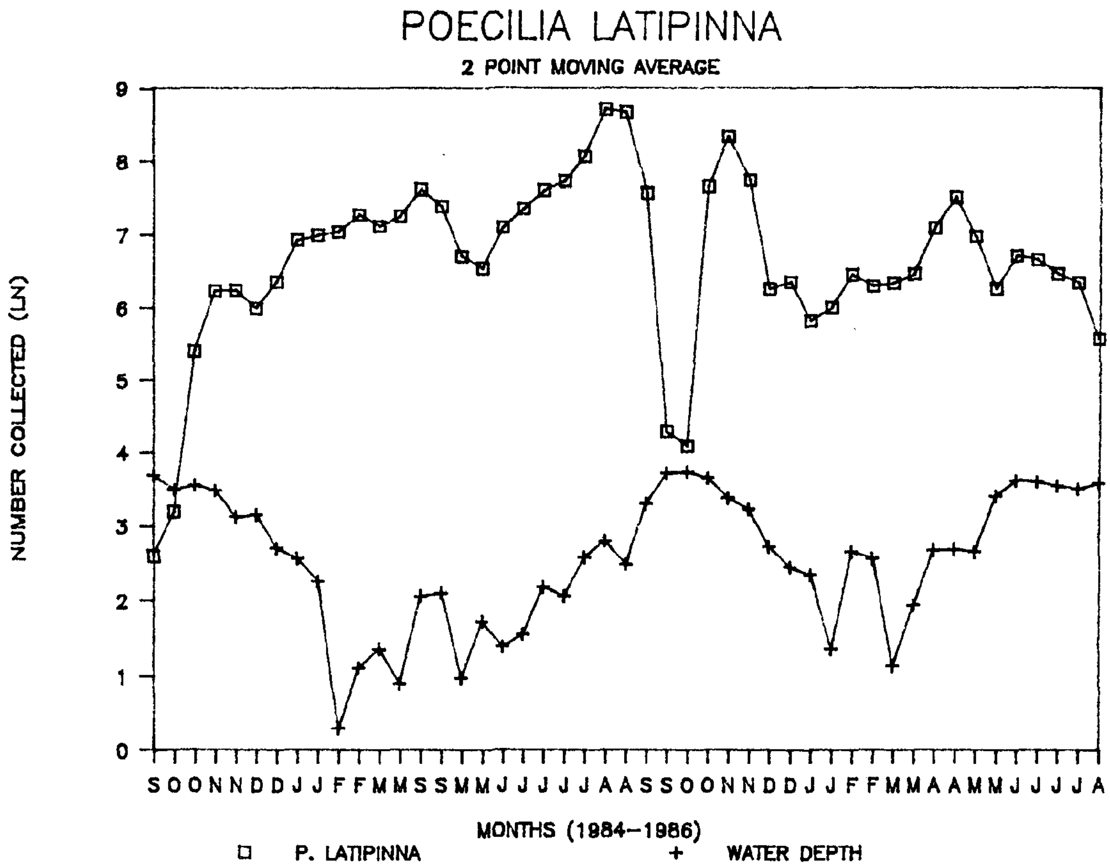

POECILIA LATIPINNA
2 POINT MOVING AVERAGE
NUMBER COLLECTED (LN)
9
8
7
6
5
4
3
2
1
0
S O O N N D D J J F F M M S S M M J J J J J A A S S O O N N D D J J F F M M A A M M J J J J A
MONTHS (1984–1986)
P. LATIPINNA
WATER DEPTH

Fig. 3

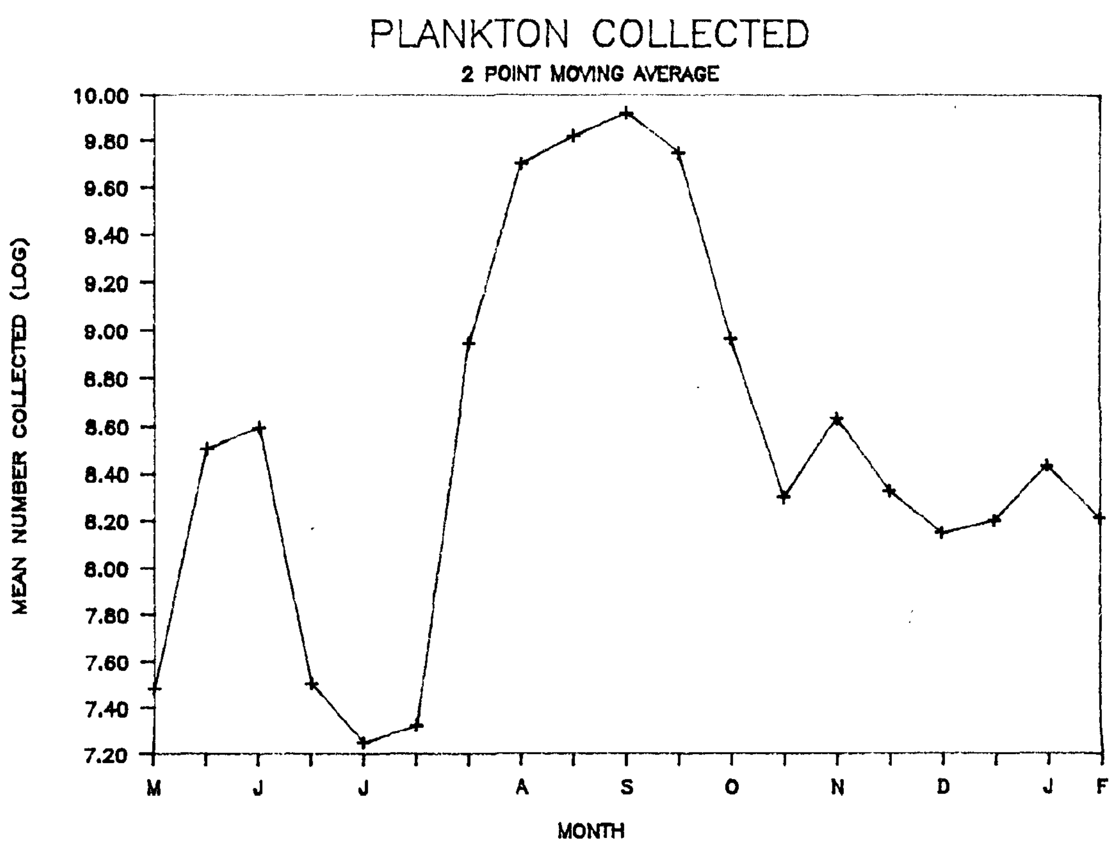

PLANKTON COLLECTED
2 POINT MOVING AVERAGE
MEAN NUMBER COLLECTED (LOG)
10.00
9.80
9.60
9.40
9.20
9.00
8.80
8.60
8.40
8.20
8.00
7.80
7.60
7.40
7.20
M
J
J
A
S
O
N
D
J
F
MONTH

Fig. 4

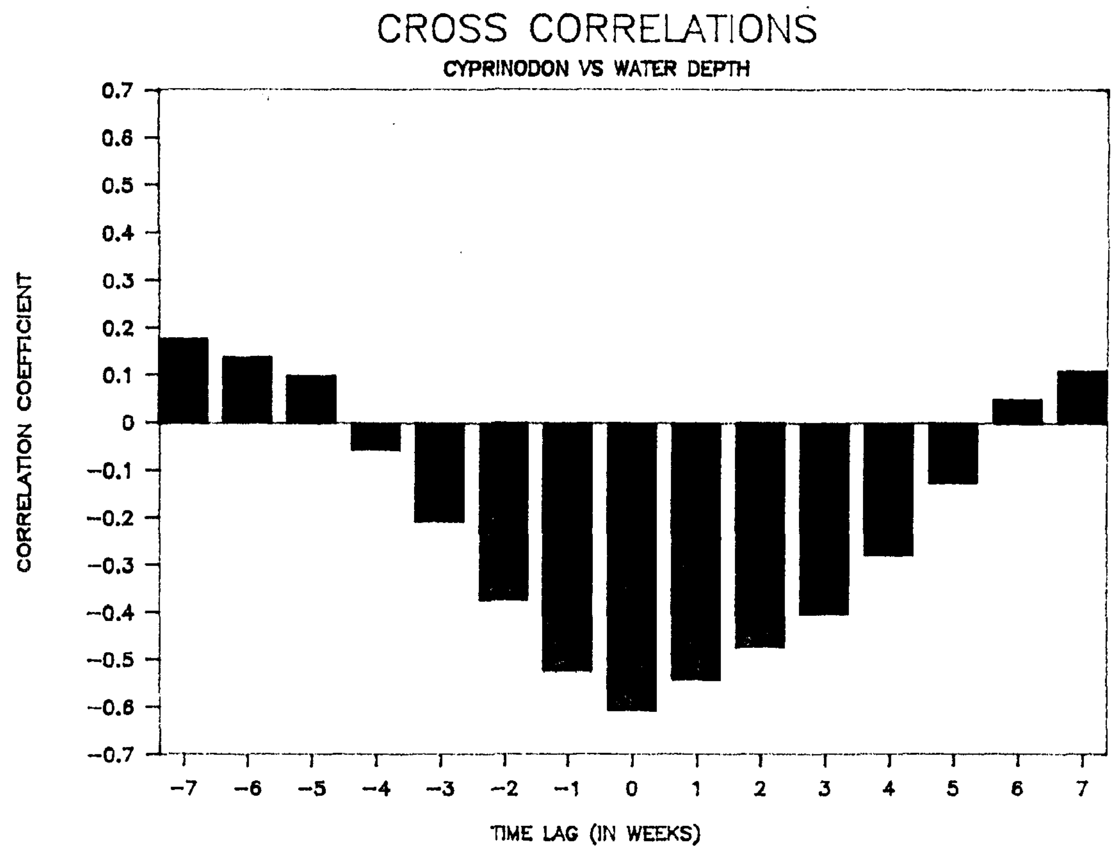

CROSS CORRELATIONS
CYPRINODON VS WATER DEPTH
CORRELATION COEFFICIENT
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7
TIME LAG (IN WEEKS)

Fig. 5

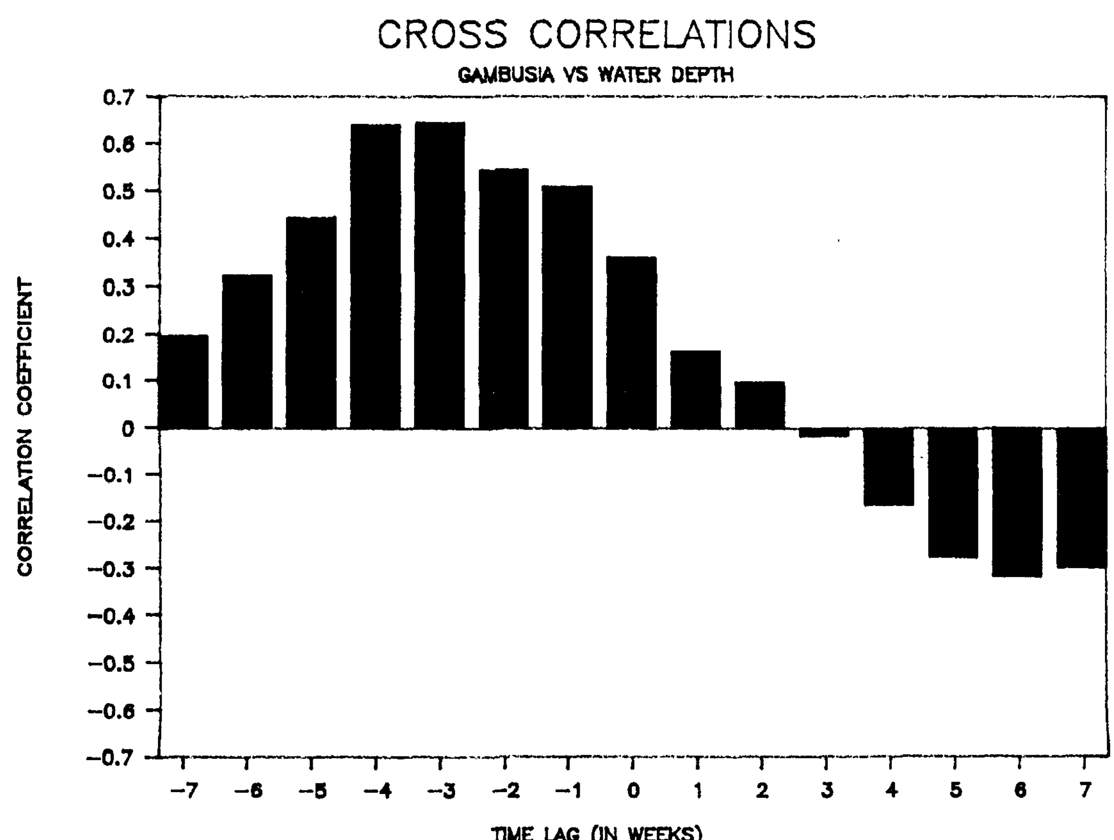
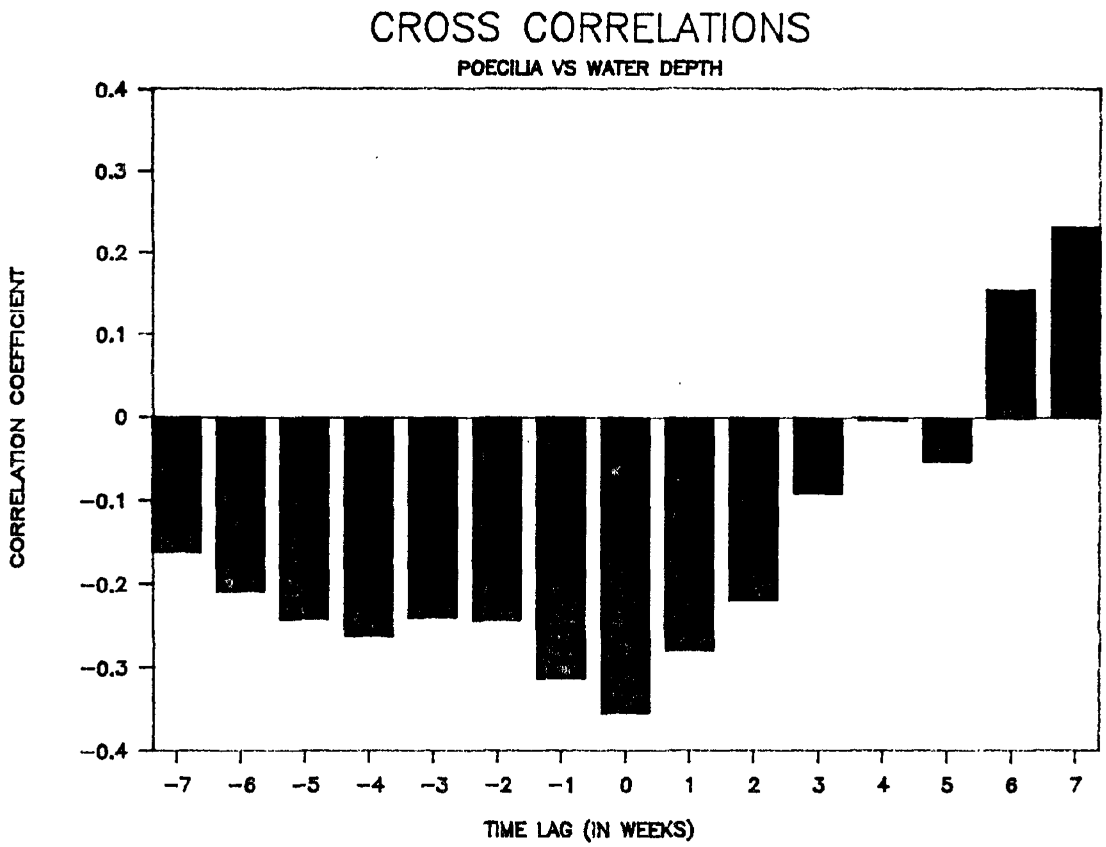

CROSS CORRELATIONS
GAMBUSIA VS WATER DEPTH
CORRELATION COEFFICIENT
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7
TIME LAG (IN WEEKS)

Fig. 6



CROSS CORRELATIONS
POECILIA VS WATER DEPTH
CORRELATION COEFFICIENT
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-7
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
TIME LAG (IN WEEKS)

Fig. 7

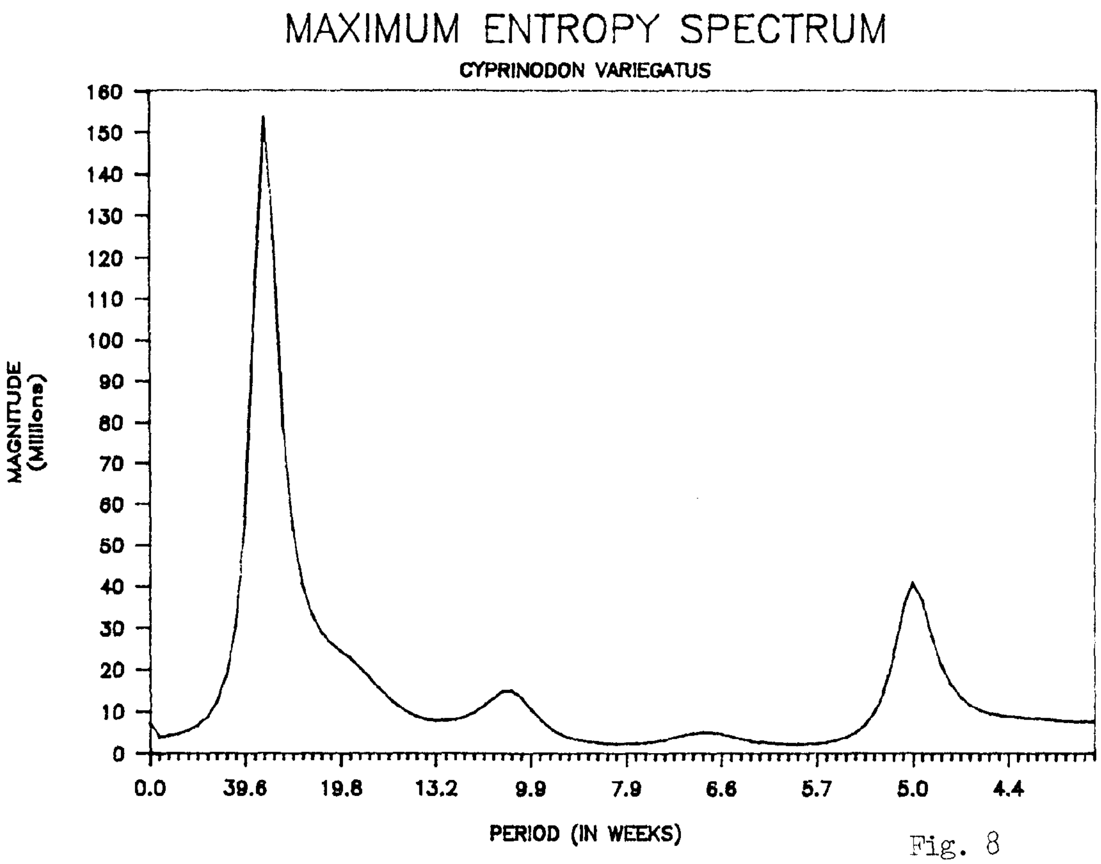

MAXIMUM ENTROPY SPECTRUM
CYPRINODON VARIEGATUS
MAGNITUDE (Millions)
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0.0
39.6
19.8
13.2
9.9
7.9
6.6
5.7
5.0
4.4
PERIOD (IN WEEKS)

Fig. 8

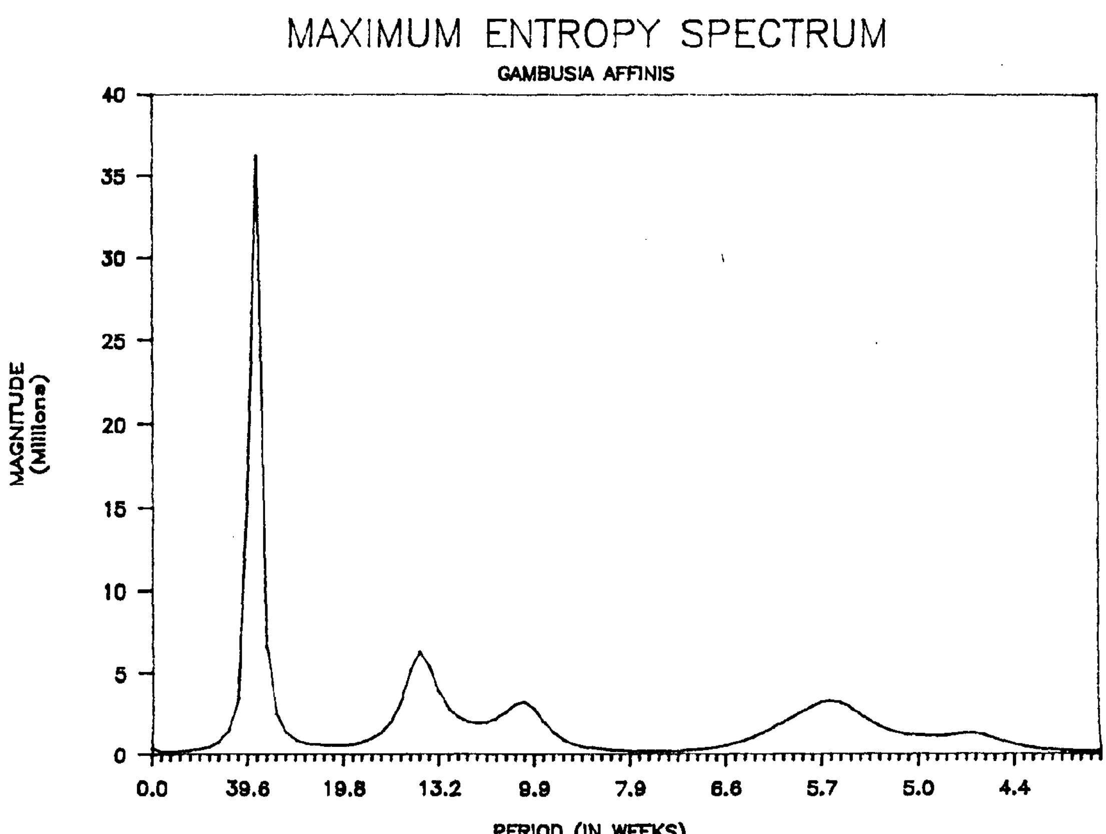

MAXIMUM ENTROPY SPECTRUM
GAMBUSIA AFFINIS
MAGNITUDE (Millions)
40
35
30
25
20
15
10
5
0
0.0
39.6
19.8
13.2
9.9
7.9
6.6
5.7
5.0
4.4
PERIOD (IN WEEKS)

Fig. 9

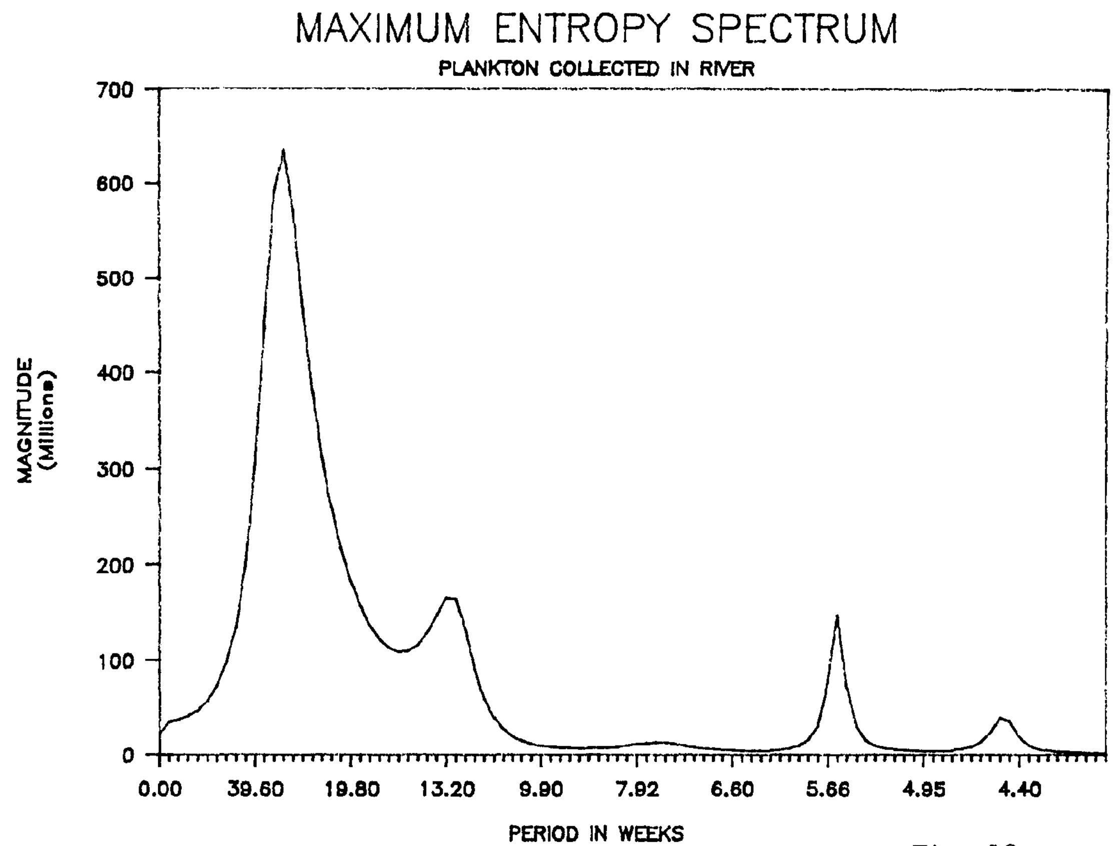
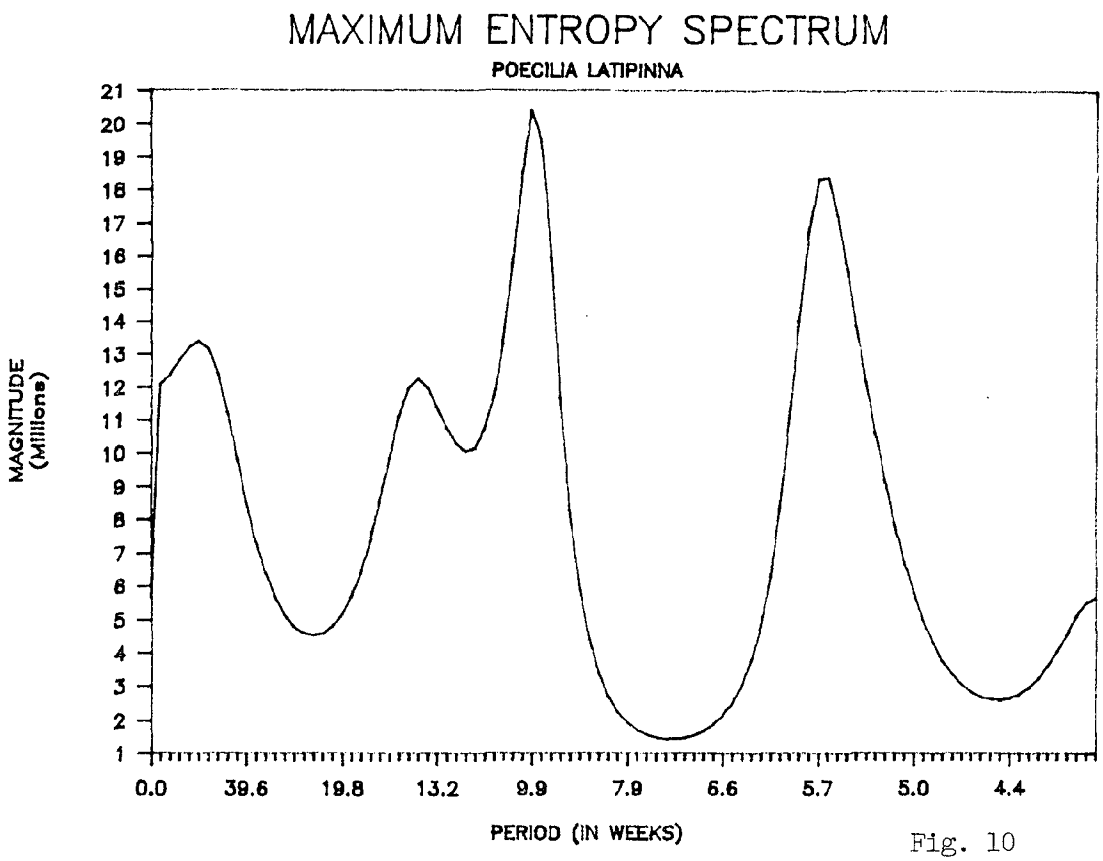
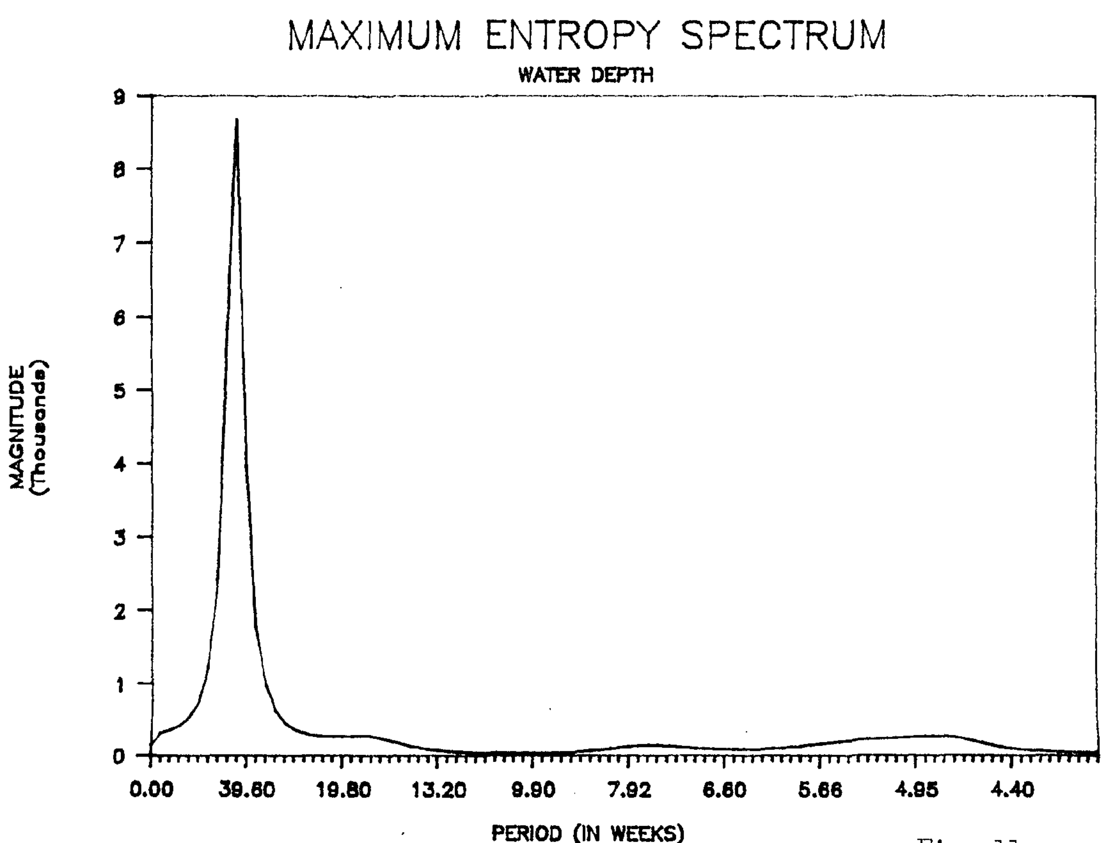

MAXIMUM ENTROPY SPECTRUM
PLANKTON COLLECTED IN RIVER
MAGNITUDE (Millions)
700
600
500
400
300
200
100
0
0.00
39.60
19.80
13.20
9.90
7.92
6.60
5.66
4.95
4.40
PERIOD IN WEEKS

Fig. 12


MAXIMUM ENTROPY SPECTRUM
POECILIA LATIPINNA
MAGNITUDE (Millions)
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0.0
39.6
19.8
13.2
9.9
7.9
6.6
5.7
5.0
4.4
PERIOD (IN WEEKS)
Fig. 10


MAXIMUM ENTROPY SPECTRUM
WATER DEPTH
MAGNITUDE (Thousands)
9
8
7
6
5
4
3
2
1
0
0.00
39.60
19.80
13.20
9.90
7.92
6.60
5.66
4.95
4.40
PERIOD (IN WEEKS)
Fig. 11

E

SEAGRASS MAPS OF THE INDIAN RIVER LAGOON

FINAL REPORT
September 1986

by

Robert W. Virnstein
and
Kalani D. Cairns

Seagrass Ecosystems Analysts
805 E. 46th Place
Vero Beach, Florida 32963

ABSTRACT

Seagrasses were mapped along a 50-mile section of the Indian River lagoon from St. Lucie Inlet to Sebastian Inlet in 1986. Large-format color aerial photographs were taken in April, followed by extensive ground-truthing between May and August. Seagrass cover was separated into four density classes. Combining clear overlays of ground-truthing information with the aerial photos, we drew contours of seagrass densities. The scale of the photos and seagrass maps were all 1:24,000 (1 inch = 2,000 feet; quad scale).

Seven seagrass species were found. In relative order of abundance, these are: manatee grass, *Syringodium filiforme*; shoal grass, *Halodule wrightii*; Johnson's seagrass, *Halophila johnsonii*; turtle grass, *Thalassia testudinum*; paddle grass, *Halophila decipiens*; star grass, *Halophila englemanni*; and widgeon grass, *Ruppia maritima*. The most extensive and lushest beds are found in northern St. Lucie County. The poorest seagrass conditions are within the city of Vero Beach. Generally, 1986 was a "good" year for seagrass, e.g., *Syringodium* and *Halophila johnsonii* are more abundant than in the previous couple of years. Many areas, however, are stressed and have lost seagrasses.

Aerial photographs, by themselves, are **not** sufficient for determining year-to-year trends in seagrass coverage. Long-term quantitative studies at permanent sites are needed, in addition to understanding basic factors that regulate seagrass distribution and abundance.

INTRODUCTION

Seagrasses are evolved from land plants back into the sea, producing one of the most productive ecosystems on earth (Zieman, 1982). Because of their sediment trapping ability, the protection they provide from erosion, their high primary productivity, and the vast quantities of trophically and commercially important consumers, for which they provide food and shelter, seagrasses are extremely important to the ecology and the economy.

As rooted plants, they require high levels of light (more than most algae) and sediments for both attachment and nutrition (algae, by contrast, get their nutrients from the water column). Thus they are restricted to a narrow band of shallow coastal waters where the often conflicting demands of man (e.g., for recreation, fisheries, and waste disposal) are the greatest threat (Thayer et al., 1975).

Although the ecological importance of seagrass habitats is well documented, the extent of seagrass coverage and year-to-year changes in the Indian River lagoon was largely unknown. Thus, this project was undertaken to determine the present status of seagrass beds in a 51-mile stretch of the Indian River lagoon from St. Lucie Inlet to Sebastian Inlet. Concurrently, Conrad White of Brevard County mapped seagrasses in the northern half of the Indian River lagoon plus the Banana River lagoon. We coordinated our studies so that results should be comparable throughout the lagoon.

METHODS

Aerial photographs were taken on 10 April 1986 by Hamrick Aerial Surveys, Inc. of Clearwater. Because seagrasses start their spring flush of growth in March, the beds were dense in April and thus showed up well in photographs, water clarity permitting. Photographs taken during the winter, when water is often clearer but when seagrasses usually lose most of their blades, would not offer this advantage. We used true color positive transparency film in 9-inch format, taken at 1:24,000 scale (1 inch = 2,000 feet: quadrangle scale of USGS topographic maps).

For most areas, these photographs showed major shallow-water seagrass beds. However, these photographs did **not** show seagrasses well in many instances: (1) where water was quite turbid, even with dense shallow beds present; (2) in deeper areas, >2-4 feet, depending on turbidity; (3) in areas of very sparse seagrass (<10% cover); (4) where the diminutive *Halophila* spp. dominated. Also, it was impossible to distinguish the various seagrass species apart or seagrass from algae. In all these instances, ground-truthing was an absolute necessity.

We concentrated our ground-truthing efforts on determining what the photographs **don't** show, e.g., the outer limits of seagrass distribution, including those areas of very sparse and patchy seagrass — a clump here, a few blades there. This was the most difficult category to determine boundaries for, but is an important category because it indicates areas where seagrasses **can** grow and have been growing. Our other emphasis was accumulating information necessary for correct interpretation of the aerial photographs — e.g., whether a dark patch in the photo was seagrass, algae, or a deep area.

For use in the field, color contact prints were made, keeping the original 1:24,000 scale. These prints provided an invaluable aid for ground-truthing, both for navigational purposes and as a medium for recording ground-truthing information. Prints were inserted into photo album pages with clear plastic overlays onto which ground-truthing information and other field notes were written directly with a fine-point permanent marking pen (e.g., "Sharpie").

In the field, limited ground-truthing information was collected by direct observation from the boat. Because of general low water clarity, however, the vast majority of observations had to be made by a diver in the water. For these observations, we used a standard diver's sled -- a small board with handles -- towed slowly behind a boat. By tilting the board, the diver could go either along the surface or along the bottom. While cruising just above the bottom, the diver would make observations of seagrass density and species composition. This information was relayed to the boat by hand signals every time the diver surfaced for a breath (SCUBA was not used, only mask and snorkel). The boat driver or observer then recorded this information on the photo overlays.

Observations were made along pre-selected transects, usually between two points visible both in the field and in the photos. Locations of transects were chosen to most efficiently (1) determine seagrass boundaries not shown by aerial photos and (2) interpret ambiguous areas of aerial photos. Generally, we ran three to four transects per mile of shoreline, but this number varied, depending on shoreline complexity and variability of seagrass cover. While I find it extremely difficult to say what constitutes "enough" transects, we felt confident that we could reasonably draw limits of seagrass density and coverage at the scale of the photos. Over this 51-mile stretch, we ran approximately 180 transects roughly perpendicular to shore (at least a dozen were longer than 1 mile) plus shoreline or spot checks in another 460 areas. Fifty days of field observations were made, over the period May through August 1986.

Four categories of seagrass density were chosen, based on a standard botanical index of percent canopy cover, from 100% cover (no sand visible) to 0% cover -- <u>1</u>: <10% cover, <u>2</u>: 10-40% cover, <u>3</u>: 40-70% cover, and <u>4</u>: >70% cover. Seagrass density estimates were based on a combination of field observations and photointerpretation.

Xerographic copies on clear film of all ground truthing information greatly aided photointerpretation. By overlaying the clear copies of ground-truthing information over the original positive transparencies on a light table, both could be viewed simultaneously. Based on the combined examination, boundaries of seagrass density zones were drawn. Where borders could not reasonably be drawn, we returned to the field to examine these areas.

The bulk of the photo-interpretation was done by Jane Provancha of the Bionetics Corporation, who drew the initial contours of seagrass density. The final map was drafted on a single strip of mylar film by Bob Walsh. Another clear overlay contains all ground-truthing information, including transects, densities, species composition, and presence of dense algae. Space did not allow the inclusion of seagrass species composition and algae distribution on the maps. All maps maintained the original 1:24,000 scale of the photographs and thus are the same scale as quad maps and the same scale as resource maps being generated by the Treasure Coast Regional Planning Council. These maps will soon be digitized by Florida DNR and incorporated into the state-wide inventory. Future reductions to a scale of 1:40,000 as clear overlays is recommended (matching the scale of NOAA navigational charts), but is outside the scope of the present budget.

The scale of the mapping limits the scale of detail presented. For example, at map scale, a seagrass patch 60 feet across would be the size of a period in this report. Therefore, it must be understood that the areas delimited by the maps represent broad areas of a given **average** seagrass density and not necessarily uniform coverage. Within all these areas, patches of both dense seagrass and bare sand occur. In both the field ground-truthing and the photointerpretation, we have tried to delimit areas that represent the same conditions over a drawable area.

I must acknowledge a cadre of volunteers who helped with the ground-truthing and map drafting. I am especially indebted to Barb Gustafson, John Arena, and Bob Walsh, without whose help this project would not have been completed. Other volunteers included George Bunnell, Derek Tremain, and Lee Mitchell. In addition, both Aquatic Preserves managers (Liberta Poolt in the south portion and Patty Carbonara in the north portion) were actively involved with the ground-truthing and format of the final product.

RESULTS

We found seven species of seagrasses in the lagoon -- all that are reported from the state. In approximate order of decreasing abundance, these are: manatee grass, Syringodium filiforme; shoal grass, Halodule wrightii; Johnson's seagrass, Halophila johnsonii; turtle grass, Thalassia testudinum; paddle grass, Halophila decipiens; star grass, Halophila englemanni; and widgeon grass, Ruppia maritima.

All species occur throughout this region of the lagoon, but not in a uniform pattern over all areas. Seagrasses barely penetrate into the St. Lucie River and not at all into the Sebastian River. The worst water quality and seagrass conditions are near the city of Vero Beach (miles 33-38). Here, water is almost always turbid, and only widely scattered patches of seagrass are found around spoil islands. The lushest beds are between Ft. Pierce Inlet and the southern end of Indian River County (miles 23-32)).

Patterns of distribution were more obvious with respect to depth and water clarity than to any north-south pattern or to any pattern of distance from an inlet. No seagrasses occur in the intertidal zone where they are regularly exposed. Heat stress may be more of a limiting factor than dessication; at the shallow margins of Halodule beds on a low tide at midday in July, water temperatures exceeded 41^{o}C (=106^{o}F). Halodule, the second most abundant seagrass, generally dominates in the shallowest zone — from just below intertidal to a depth of a foot or so. Halodule is often the most abundant seagrass, although occurring sparsely, also at the deepest margins. Syringodium, the most abundant seagrass, generally is densest and dominant in mid-depths -- from just below Halodule, if present, to 3 feet deep. Blades of Syringodium are in some places up to 3 feet long. Halophila johnsonii, although originally described from intertidal shoals, is the dominant seagrass in the deepest areas of several regions and is often abundant in extremely turbid water. It apparently can tolerate lower light levels than other seagrasses. Halophila decipiens, very similar to H. johnsonii in size and morphology, also is abundant in deep areas, but not in Indian River County. Thalassia, the most robust species and supposedly the dominant species in a successional sense, often occurs as roughly circular monospecific beds at mid-depths but occasionally at all depths (up to 6 feet). Patches are scattered throughout the region, but Thalassia is most abundant in northern St. Lucie and southern Indian River Counties (miles 25-32). Ruppia occurs as very widely-scattered patches in shallow water (often mixed with Halodule and difficult to distinguish) and dense in one extremely turbid embayment (mile 43).

In turbid areas, these depth zones may be compressed. For example, in the Vero Beach area, seagrasses do not occur deeper than about 2 feet. Sharp seagrass boundaries may occur here with depth differences of only a few inches.

We had several pleasant surprises from the field. In areas of higher water clarity (generally near inlets), we found seagrass growing as deep as 6 feet. Within Indian River County especially, turtle grass (Thalassia testudinum) is far more abundant than we expected, considering that its northern limit on this coast is Sebastian Inlet. Several previously sparse areas of manatee grass (Syringodium filiforme) are now dense and lush. Halophila johnsonii, recently described as a new species from small patches locally, is abundant throughout the project area, and is often the dominant seagrass in deeper areas. Halophila decipiens, previously reported from this coast only from deep-water offshore reefs, is also abundant. Because both these seagrasses are short (about 1 inch) and inconspicuous, they may have been overlooked in previous surveys by John Thompson (1976), Ken Haddad (DNR), and myself (Virnstein and Carbonara, 1985). We believe, however, that we are seeing the results of a proliferation of these two species of Halophila in the past year. Because both these species are diminutive they probably do not provide the habitat value of the larger species.

Although we do not yet have data breakdowns of coverage in each area, these maps will be digitized soon by DNR. Coverages, percents, and density category breakdowns can then be easily calculated for any portion of the mapped area.

DISCUSSION

In general, 1986 has been a "good" year for seagrass in the Indian River lagoon, and seagrasses are in good shape, compared to 2-3 years ago (personal observation). These "good" conditions (low rainfall, mild weather, and clear water) apparently occurred state-wide (personal communication from K. Haddad and R. Lewis). That is **not** to say that there are not some serious problems and stresses on seagrasses in the lagoon; in some areas, seagrass has totally disappeared from a few years ago. This report only describes the status of seagrass beds in summer, 1986. No one can predict whether next year will be a "bad" year for seagrasses. This large year-to-year variance does point up the need for a **continuing**, long-term program to study seagrasses. Only then can meaningful statements be made about trends or changes from one year to another.

Although we feel confident about the general accuracy of our boundaries, certain inaccuracies are inherent in this type of study. Because measurements were not repeated, the precision of the boundaries cannot be determined. Transects were generally spaced hundreds of yards apart, and smooth contours drawn between actual observed boundaries. There are, no doubt, unavoidable errors in this process of interpolation. The ground-truthing work is time consuming and labor intensive. Direct diver-to-boat communacation could increase accuracy of recording observations. To determine exact boundaries everywhere, however, would require an army; inconsistencies among personnel can be eliminated by standardizing categories and procedures.

To confidently determine year-to-year differences, aerial photos are **not** sufficient. Repeatable measures must be made, e.g., within several permanently marked quadrats or transects, accurately surveyed on a seasonal or yearly basis. Time series or trends based solely on photos is fraught with unknown, but possibly large, errors. What the aerial photos **don't** show may be a more important consideration than what they **do** show. Two examples of such problems include: (1) To photograph seagrasses, clear water is absolutely necessary and more critical than clear weather. But clear water usually occurs during the winter, when seagrasses may lose all their leaves and thus are not visible. Early spring, just after initial growth and before warm weather, may provide the best window for photography. A combination of seasonal photographs would be best. In our recent photos, none of the beds of Halophila were visible. (2) The second problem is that, even in the clearest photos, it is not possible to distinguish seagrass beds from accumulations of algae, either drift or attached. In the Banana River lagoon and the northernmost Indian River lagoon, there is presently far more coverage by the attached alga Caulerpa prolifera than by seagrass (White, 1986).

RECOMMENDATIONS

To properly understand seagrass dynamics, a continuing long-term monitoring and research program must be established, preferably in conjunction with similar programs in other areas throughout the state. Such a program is especially necessary to understand and interpret year-to-year changes in seagrass distribution and abundance. Two enigmas emphasize this need: (1) the past "good" year for seagrass and (2) the apparent proliferation of two species of seagrass (Halophila johnsonii and H. decipiens) and an attached alga (Caulerpa prolifera). Is this a repeating phenomenon or a one-time occurrence?

Other research emphasis should be on determining factors that regulate seagrass growth and distribution. We must answer basic questions needed for management, such as: what light levels are necessary for seagrass survival, growth, and reproduction; what levels of nutrient addition produce what levels of seagrass decline; and what are salinity tolerances of seagrasses. Only then can rational management decisions be made.

Seagrasses in the Indian River lagoon are especially vulnerable to inputs and impacts because of the lagoon's nearly-enclosed nature and poor flushing characteristics. I believe that one "bad" year could result in the loss of up to half of the present coverage of seagrass. No one knows whether such a loss would be recoverable or permanent. As of this writing, I know of **no** research being conducted on seagrasses or seagrass communities in the Indian River lagoon, despite their overwhelming importance to the ecology and the economy of the lagoon.

As a recently appointed member of the state's Seagrass Task Force, I hope I can make the state aware of the special needs of the Indian River lagoon. This DER-funded mapping study will be a very important background to bring to this committee, whose stated purpose is "to provide the department [Florida

Department of Environmental Regulation] with general advice on the status of these valuable resources, and current expertise in protecting them." This task force will be recommending that certain areas of the state, including the Indian River lagoon, because they are so vulnerable to impending impacts from man's activities, be declared critically stressed (danger areas), and immediate and severe measures must be taken to prevent further declines in seagrass beds.

I have been pleased with the reception and support for this project by the public, including strong support from local commercial fishermen. I have also tried to involve local and regional political leaders and planners in the management of seagrass beds. In presentations before county commissions in Martin, St. Lucie, and Indian River Counties (see Appendix), I hope I have made them aware of what seagrasses are, why they are important, some problems and stresses on seagrasses, and some actions that can be taken at the local level. No actions have been taken, however.

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APPENDIX III

The following is a list of presentations and press coverage about this seagrass mapping project:

April 24. Gave invited talk on "Seagrass of the Indian River lagoon" to the Vero Beach Anglers Club.

May 14. Gave invited talk on "Seagrass meadows in the Indian River lagoon" at Indian River Shores. Sponsored by the Florida Institute of Technology Marine Science Research Center.

May 18. Interview on problems confronting seagrass and video from a seagrass site was broadcast on the 6:30 news on Channel 34 (WTVX), a local CBS affiliate.

June 1. "Seagrass provides marine life oasis." Page 1 article in Vero Beach Press Journal by James Kirley.

June 4. "Lagoon's seagrasses vital to life in ecosystem." Page B5 article in Ft. Pierce/Pt. St. Lucie News Tribune by R.G. Schmidt.

June 9. Interview on value of and problems confronting seagrass and video from a seagrass site was broadcast on the 11:00 news on Channel 5 (WPTV), a local NBC affiliate.

June 10. Presentation before Martin County Commissioners concerning this mapping project, problems facing seagrasses, and a list of actions that the Commission could take.

July 7. Presentation to the St. Lucie County Commissioners concerning this mapping project, problems facing seagrasses, and a list of actions that the Commission could take.

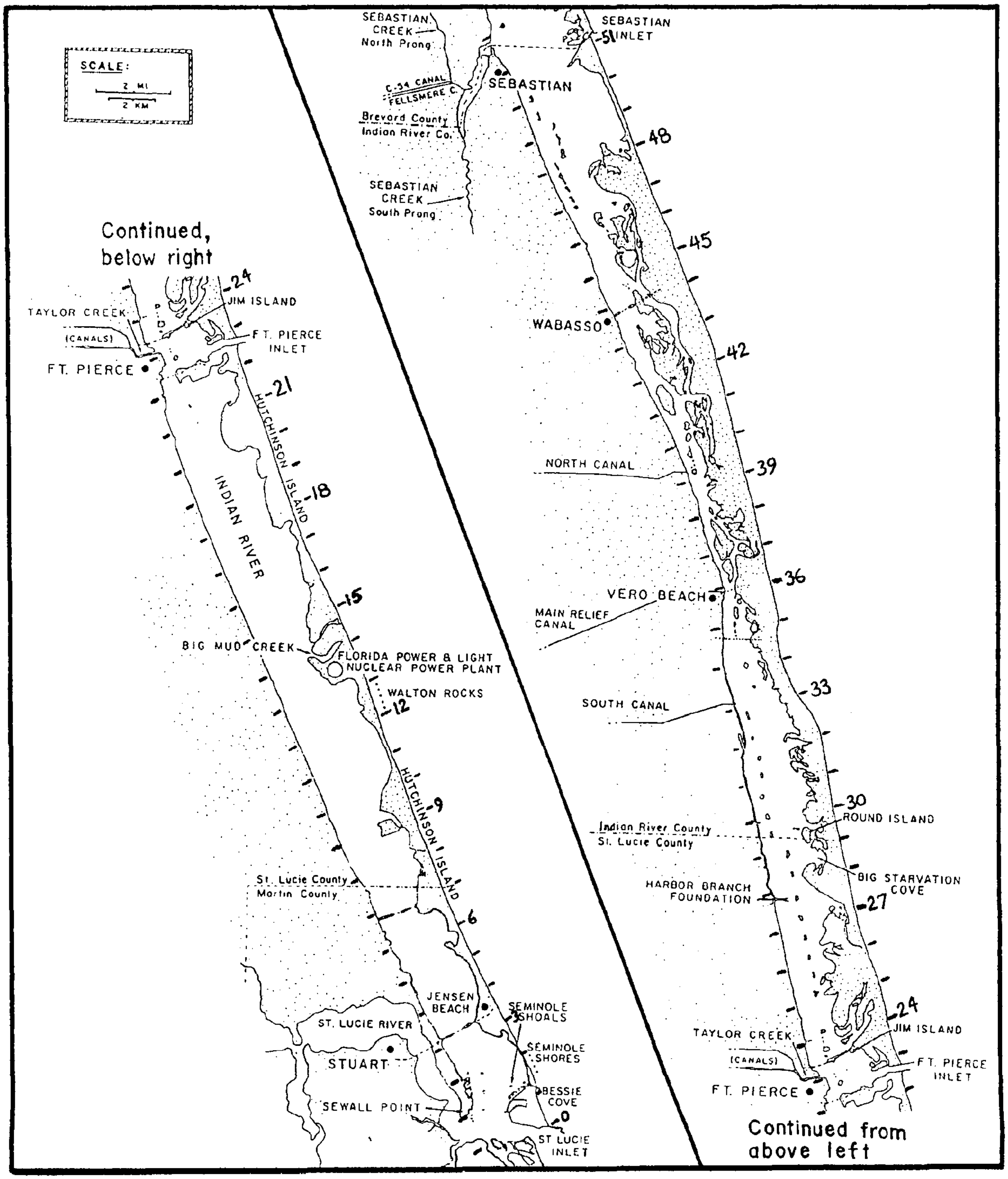
September 24. Invited talk at the quarterly luncheon meeting of the Marine Resources Council. This mapping project and problems facing seagrasses in the Indian River lagoon were discussed, including some management and research recommendations.

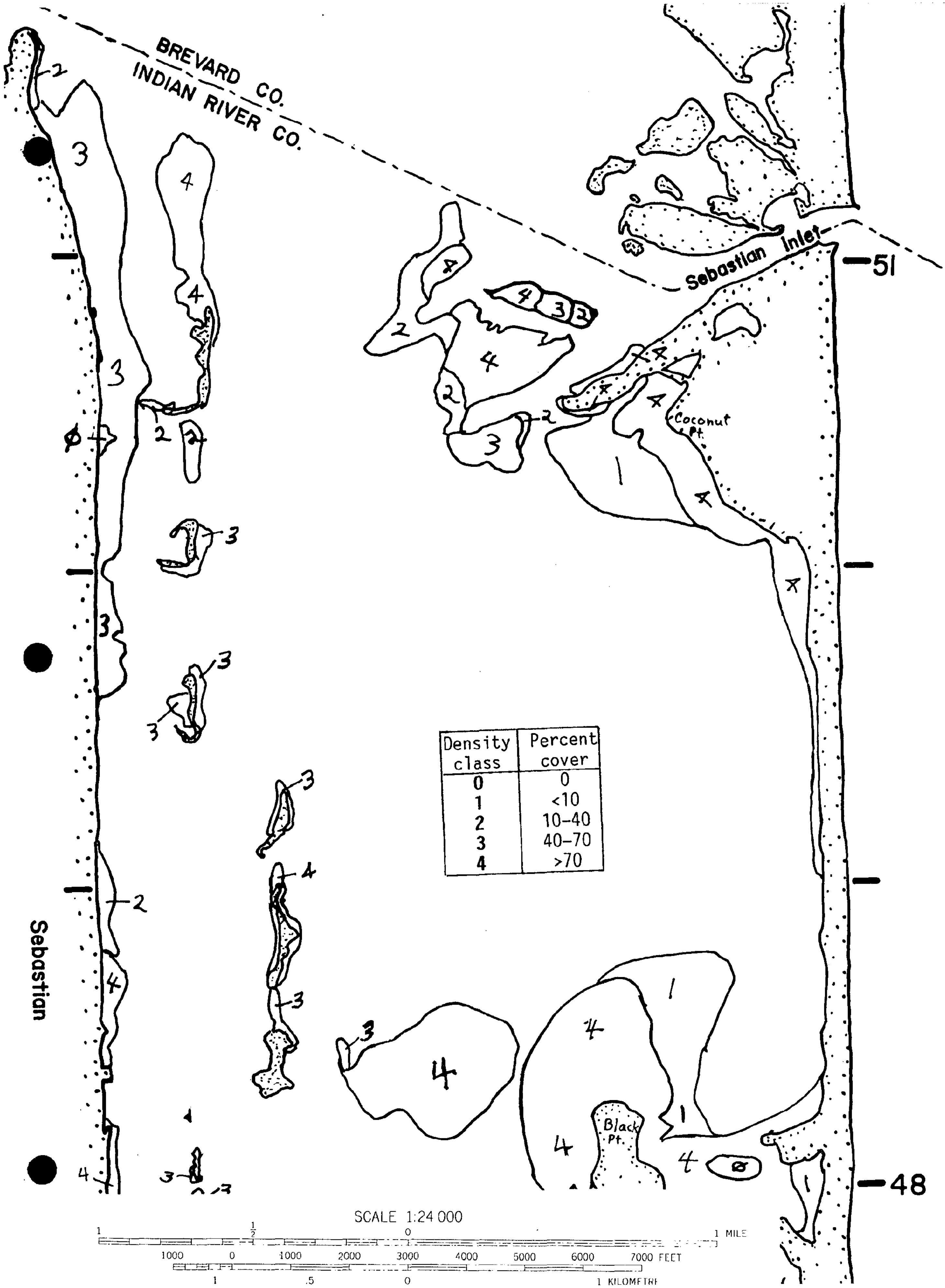
September 25. "Dirty water shades sea grass." Page 1 article in Florida Today by Peter Hooper.

September 29. Invited talk on "Seagrass beds protection" at the conference on "Florida's Coastal Future: The Challenge Remains."

THE MAP AND MAP CONVENTIONS

Boundaries are drawn of four density classes of seagrass from St. Lucie Inlet at the southern end (mile 0) to Sebastian Inlet at the northern end (mile 51). Algae are not included on the map. Original photos and ground-truthing information, including species composition, are kept on file by the author. Each page of the map covers 3^+ miles of the lagoon, starting at St. Lucie Inlet and proceeding north, 3 miles to a page, corresponding to the index map below. Seagrass map scales are all quadrangle scale (1:24,000; 1 inch = 2,000 feet).





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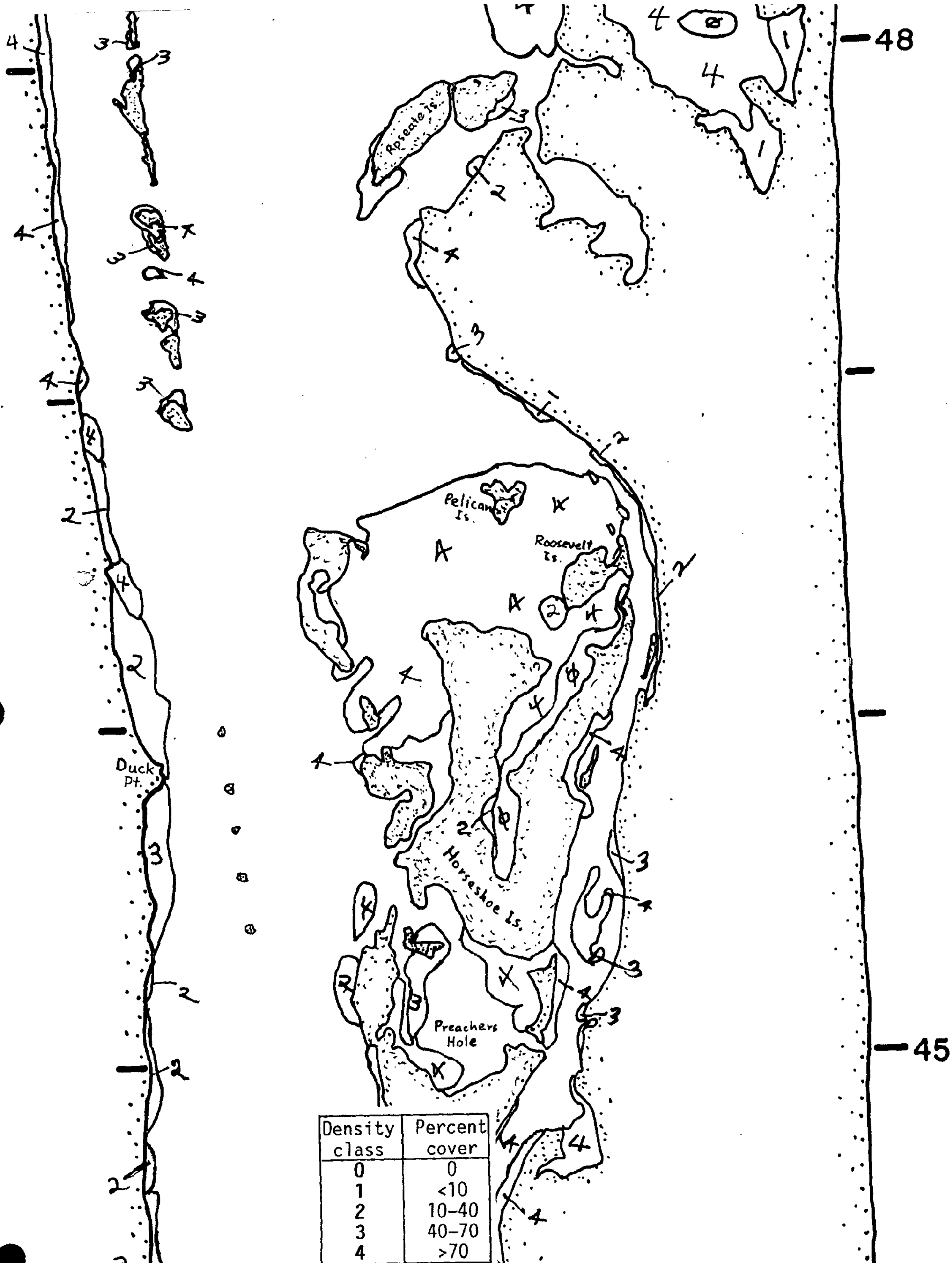
2	10–40
3	40–70
4	>70



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4	>70

SCALE 1:24 000

1 ½ 0 1 MILE

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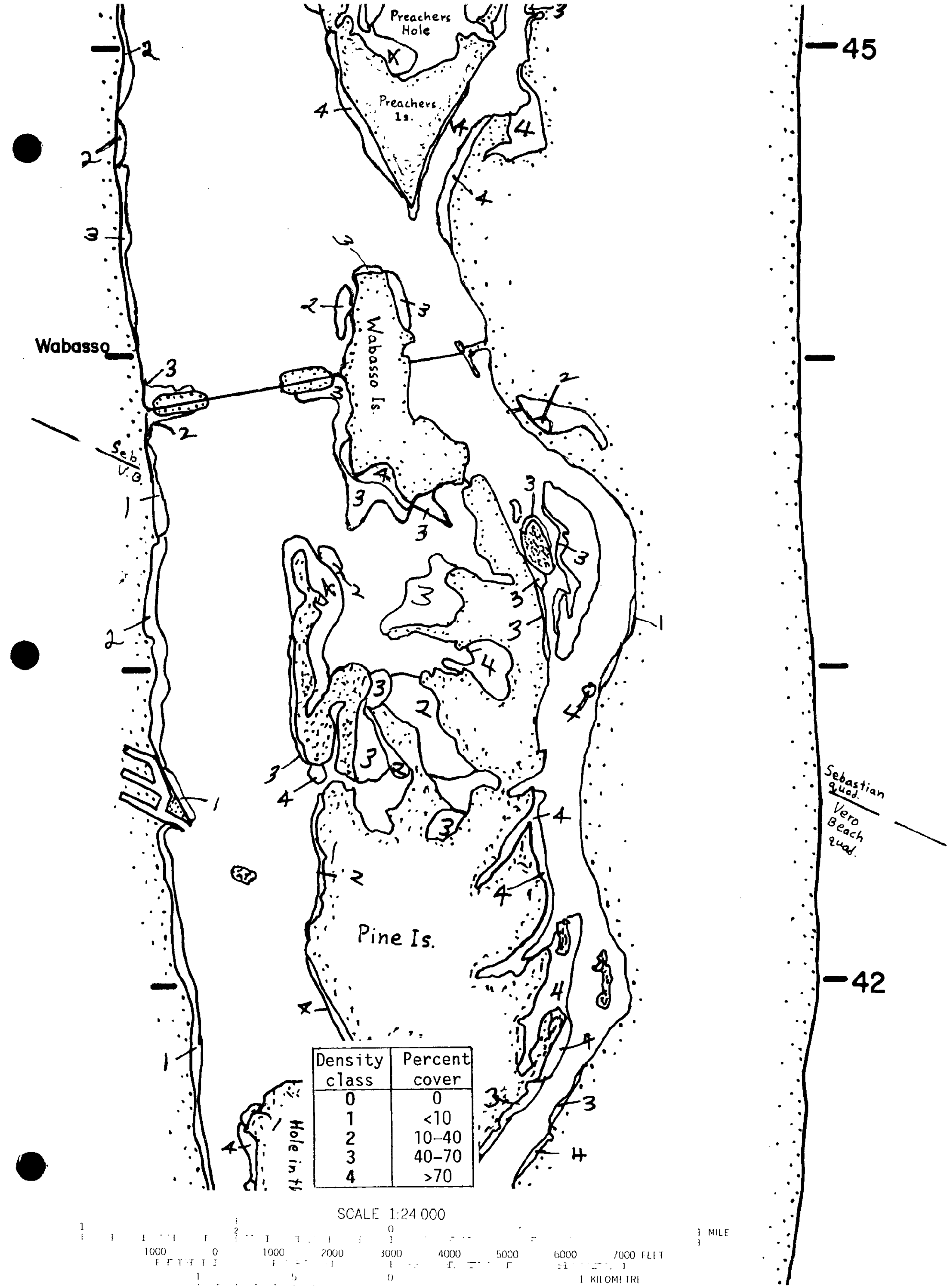
1 .5 0 1 KILOMETRE



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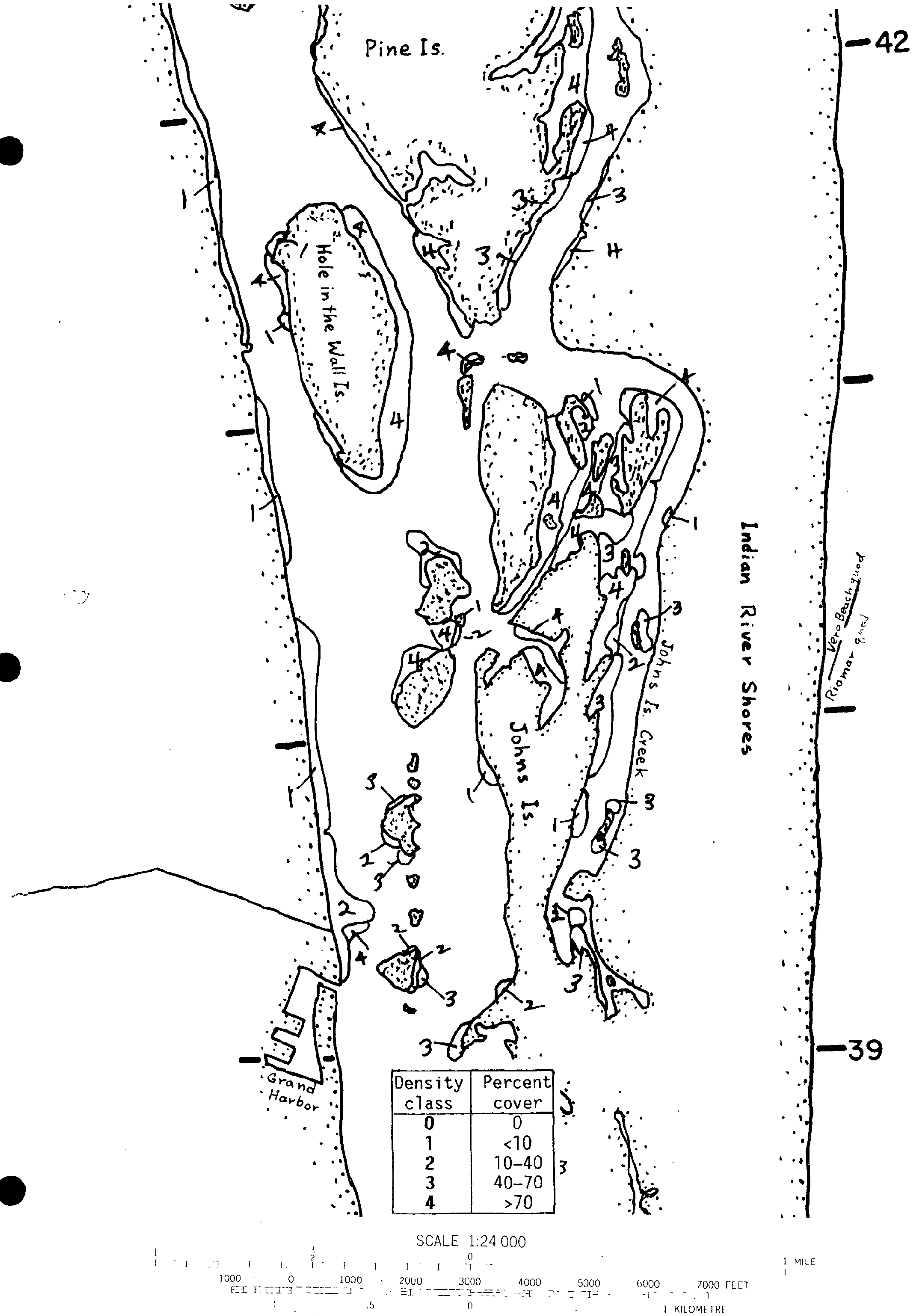

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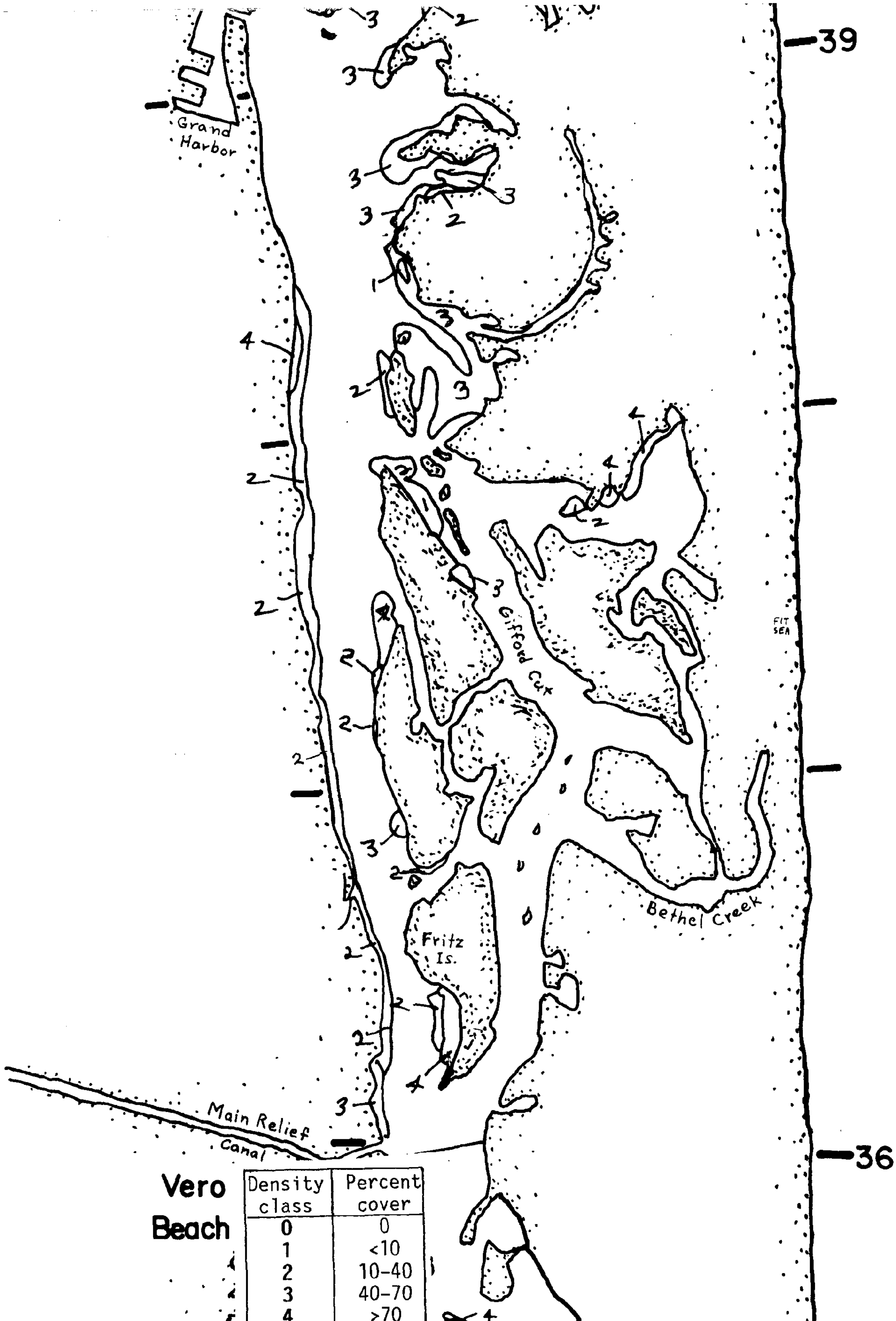

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1	<10
2	10–40
3	40–70
4	>70

SCALE 1:24 000

1 ½ 0 1 MILE

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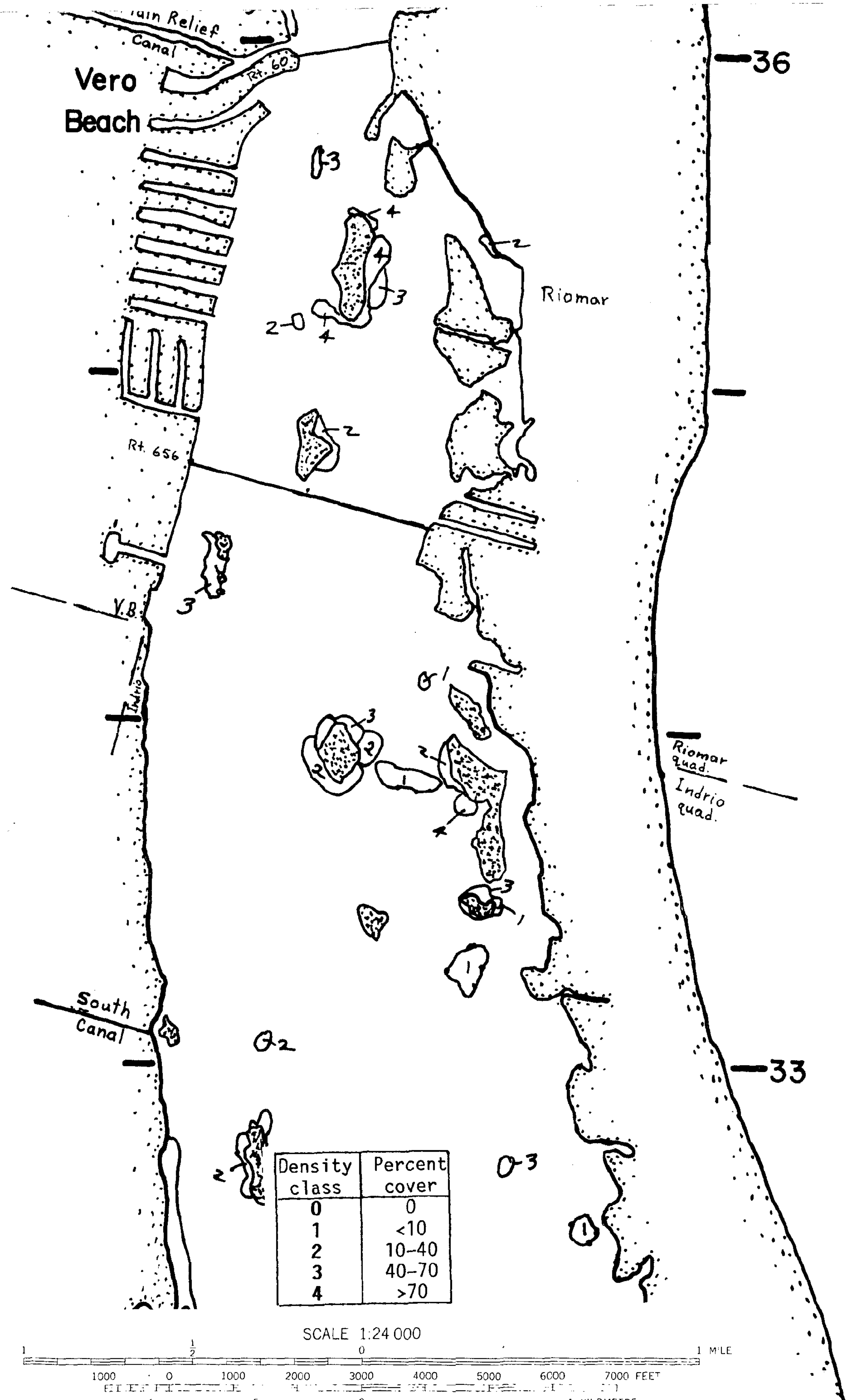
1 .5 0 1 KILOMETRE



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4	>70

Density class	Percent cover
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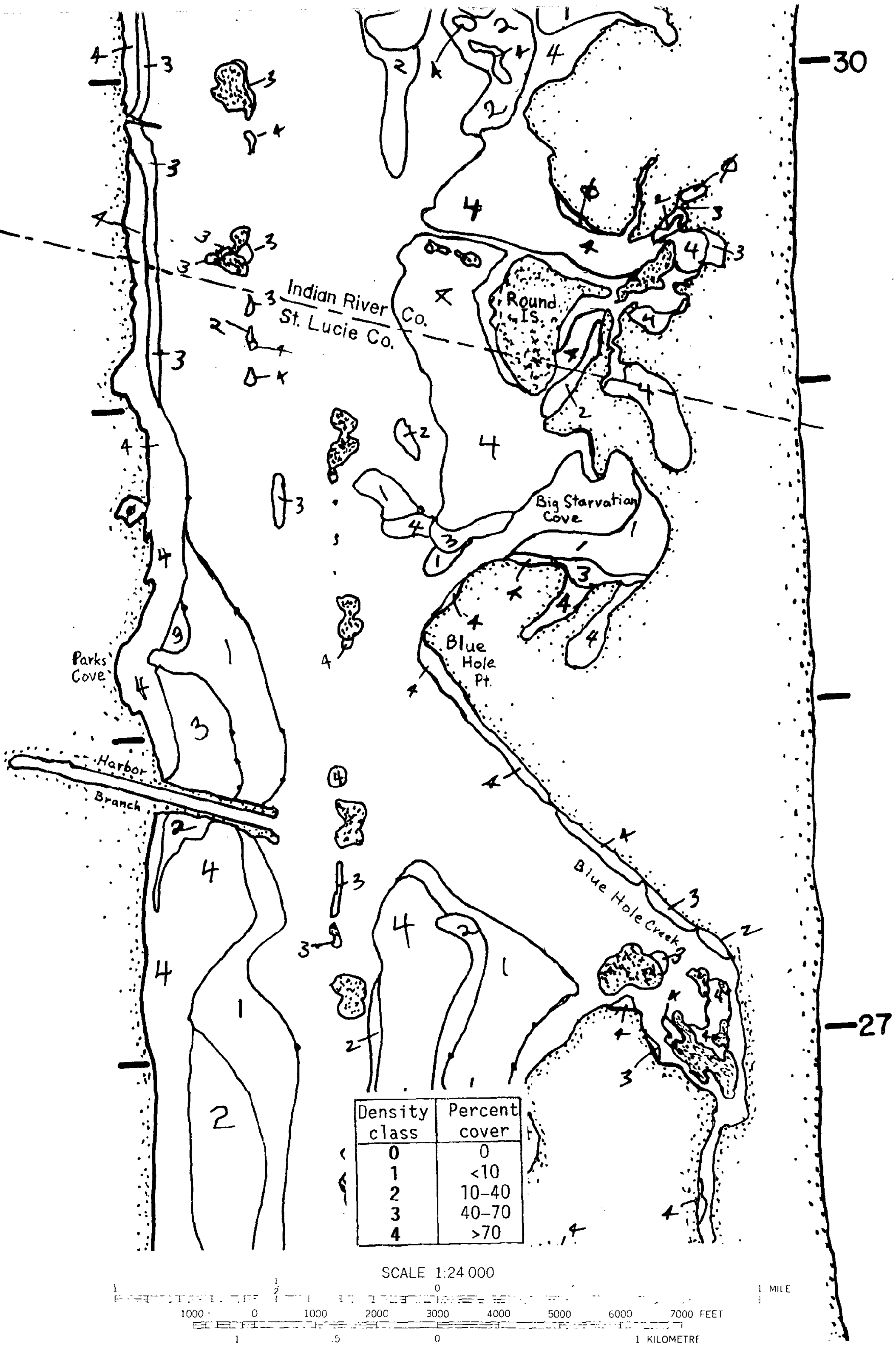
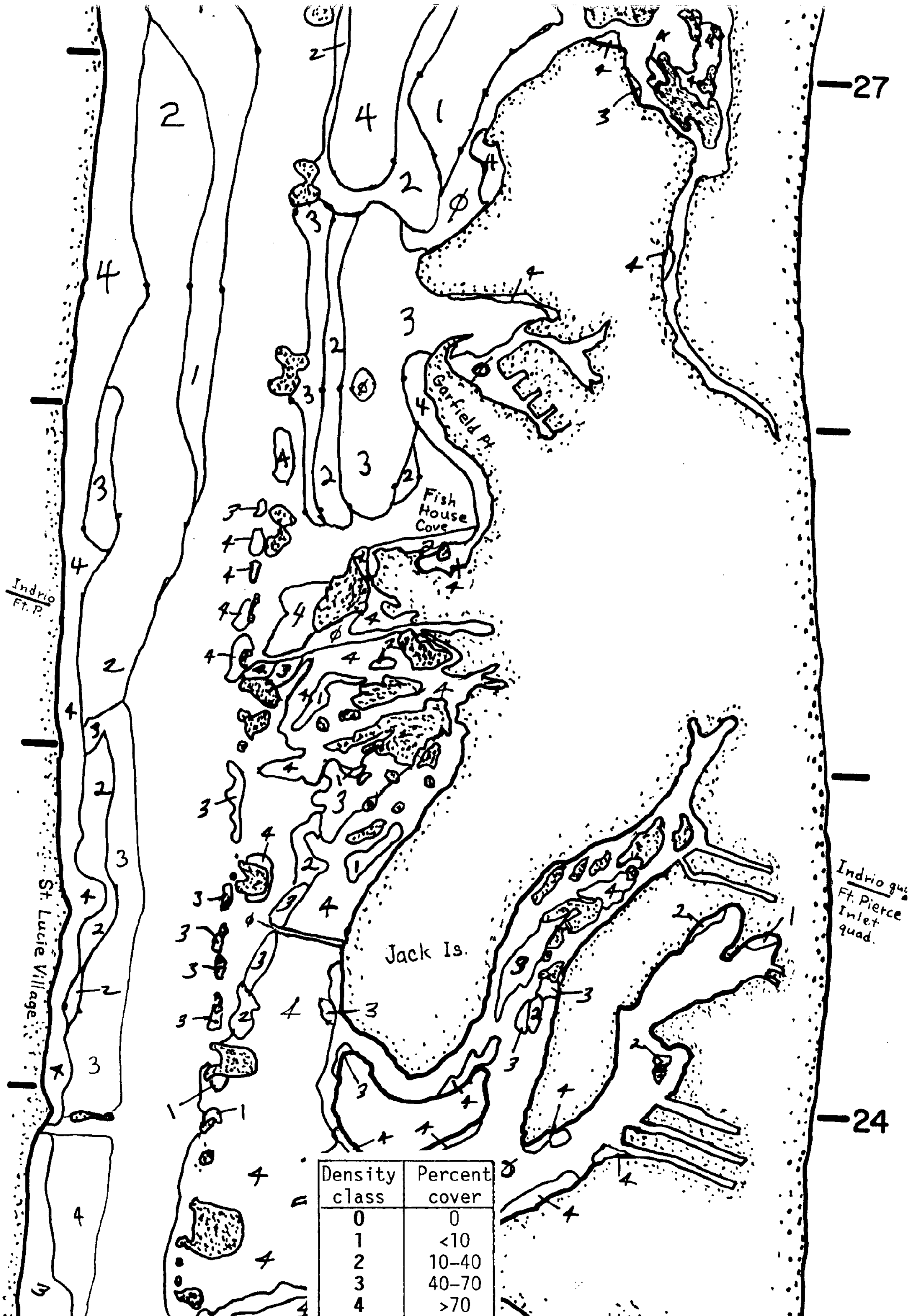
3	40–70
4	>70



30
Indian River Co.
St. Lucie Co.
Round Is.
Big Starvation Cove
Blue Hole Pt.
Parks Cove
Harbor Branch
Blue Hole Creek
27
Density class | Percent cover
0 | 0
1 | <10
2 | 10–40
3 | 40–70
4 | >70
SCALE 1:24 000
1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETRE



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3	40–70
4	>70

SCALE 1:24 000

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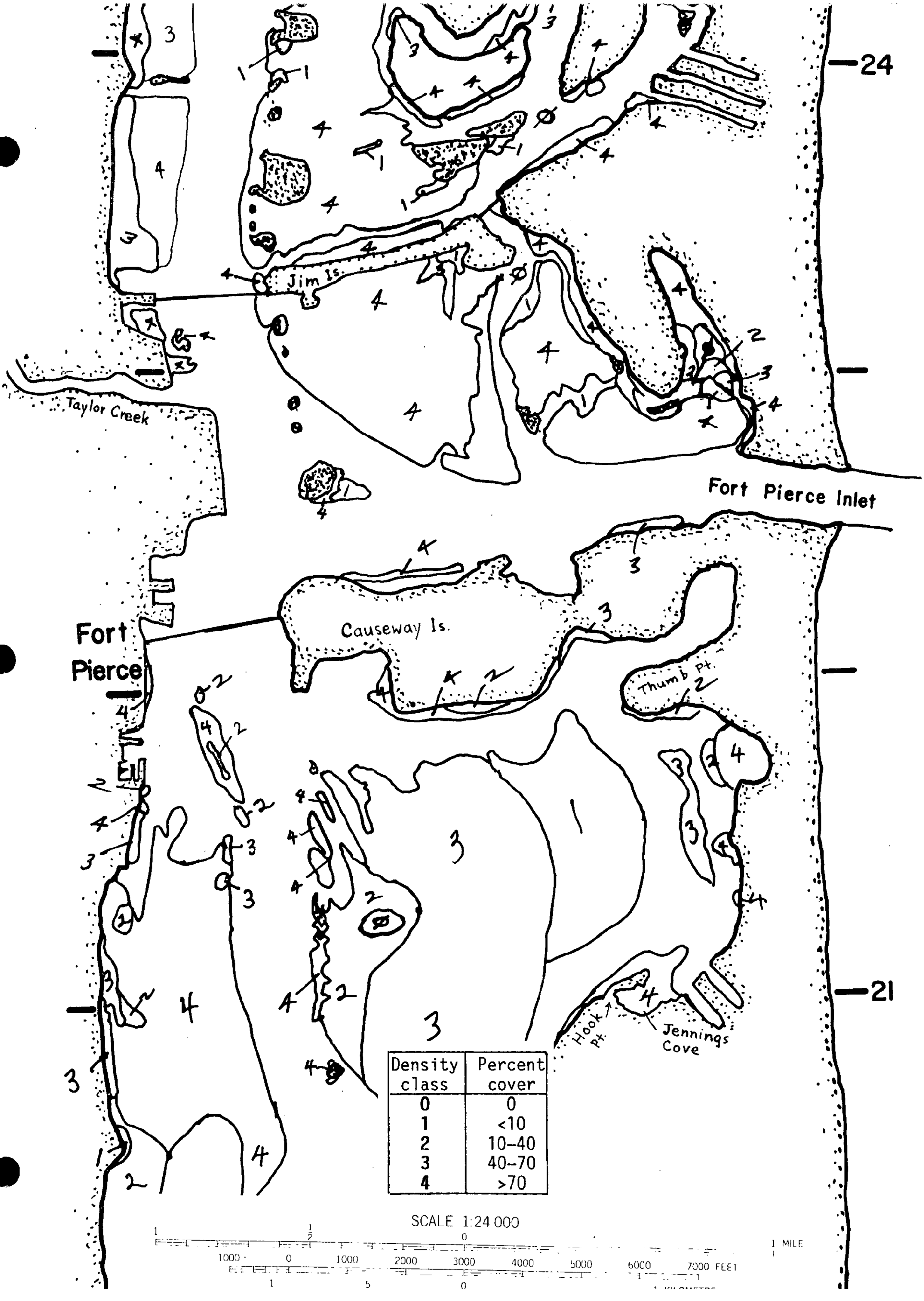
1 .5 0



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3	40–70
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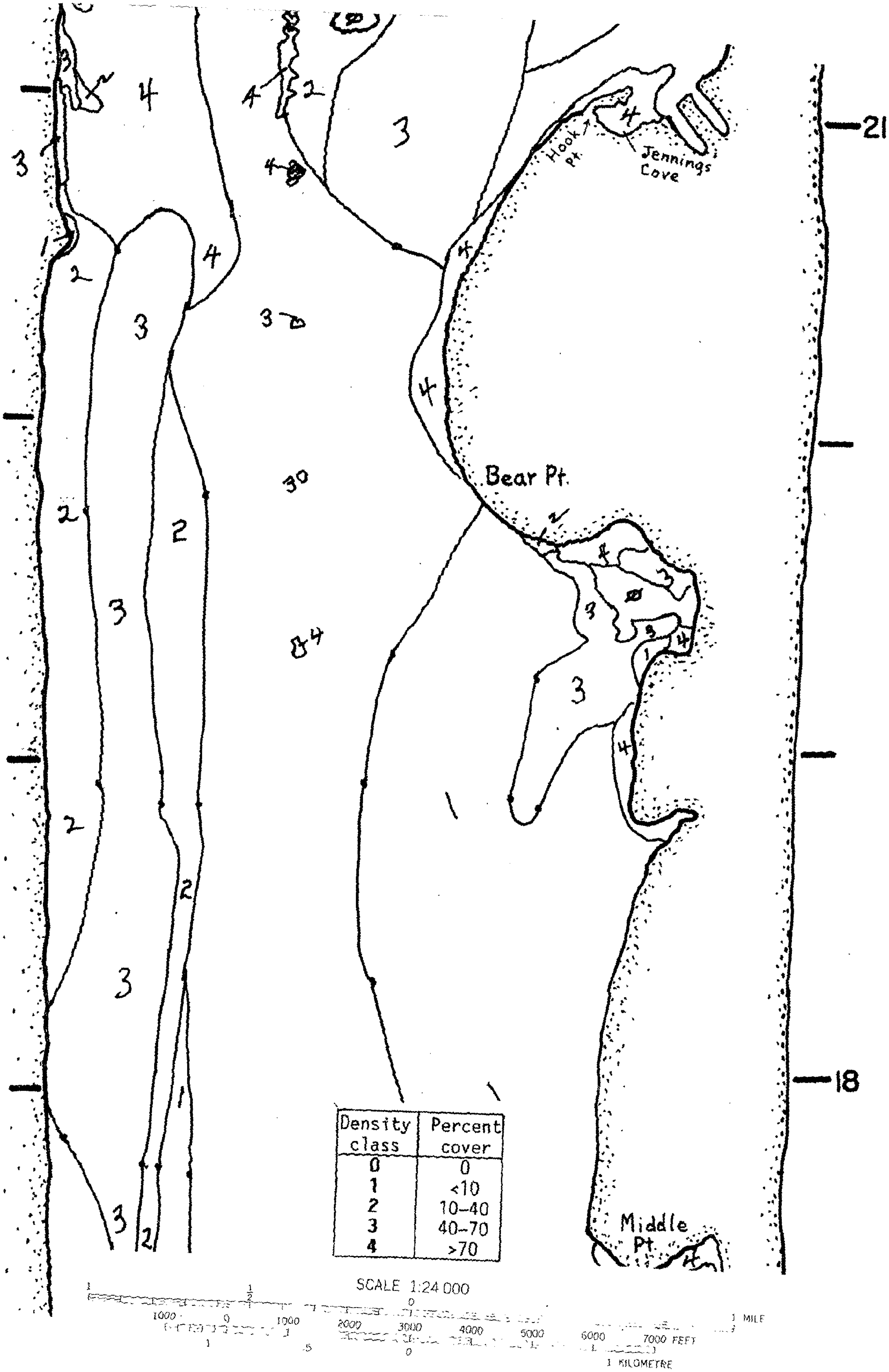

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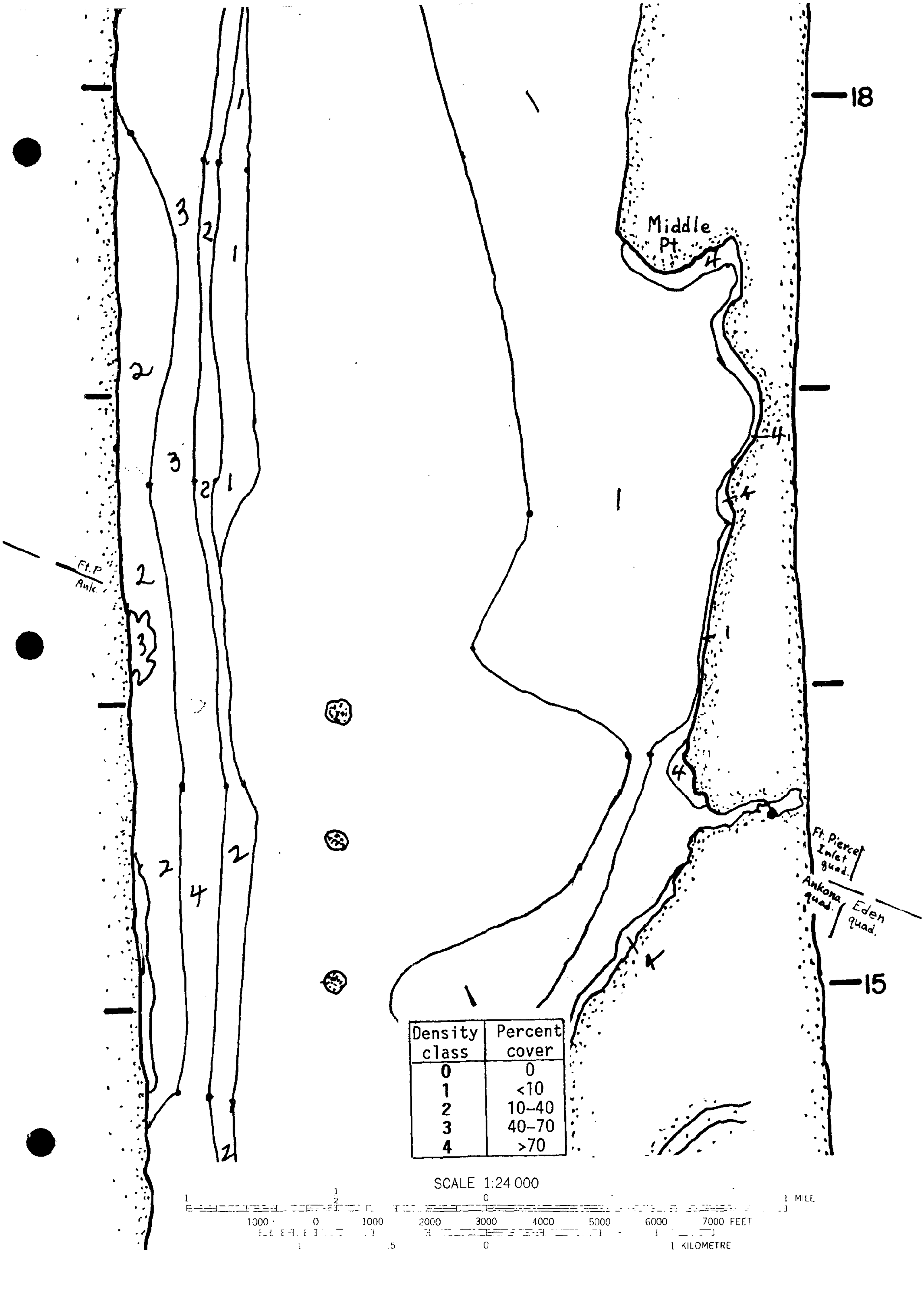

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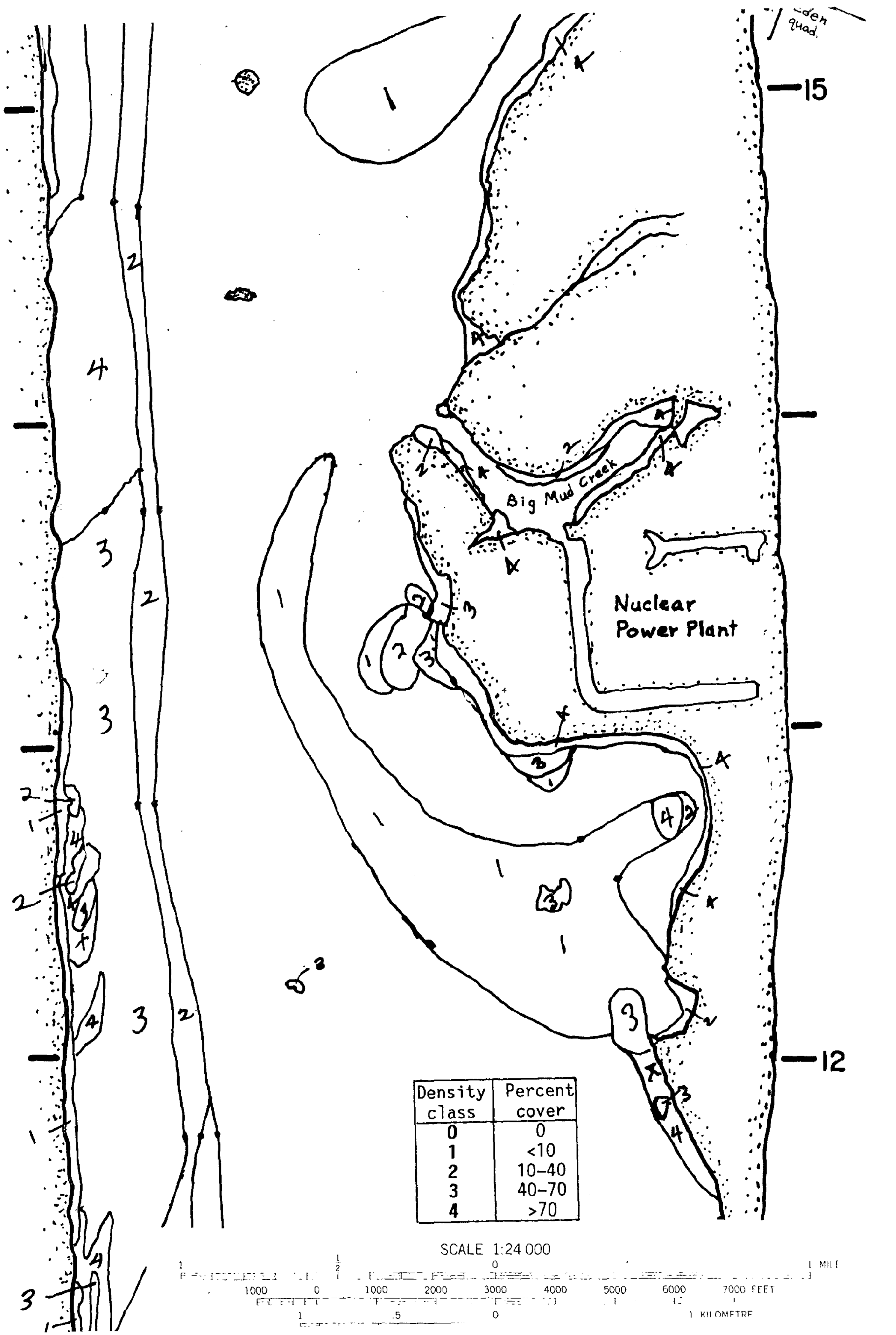

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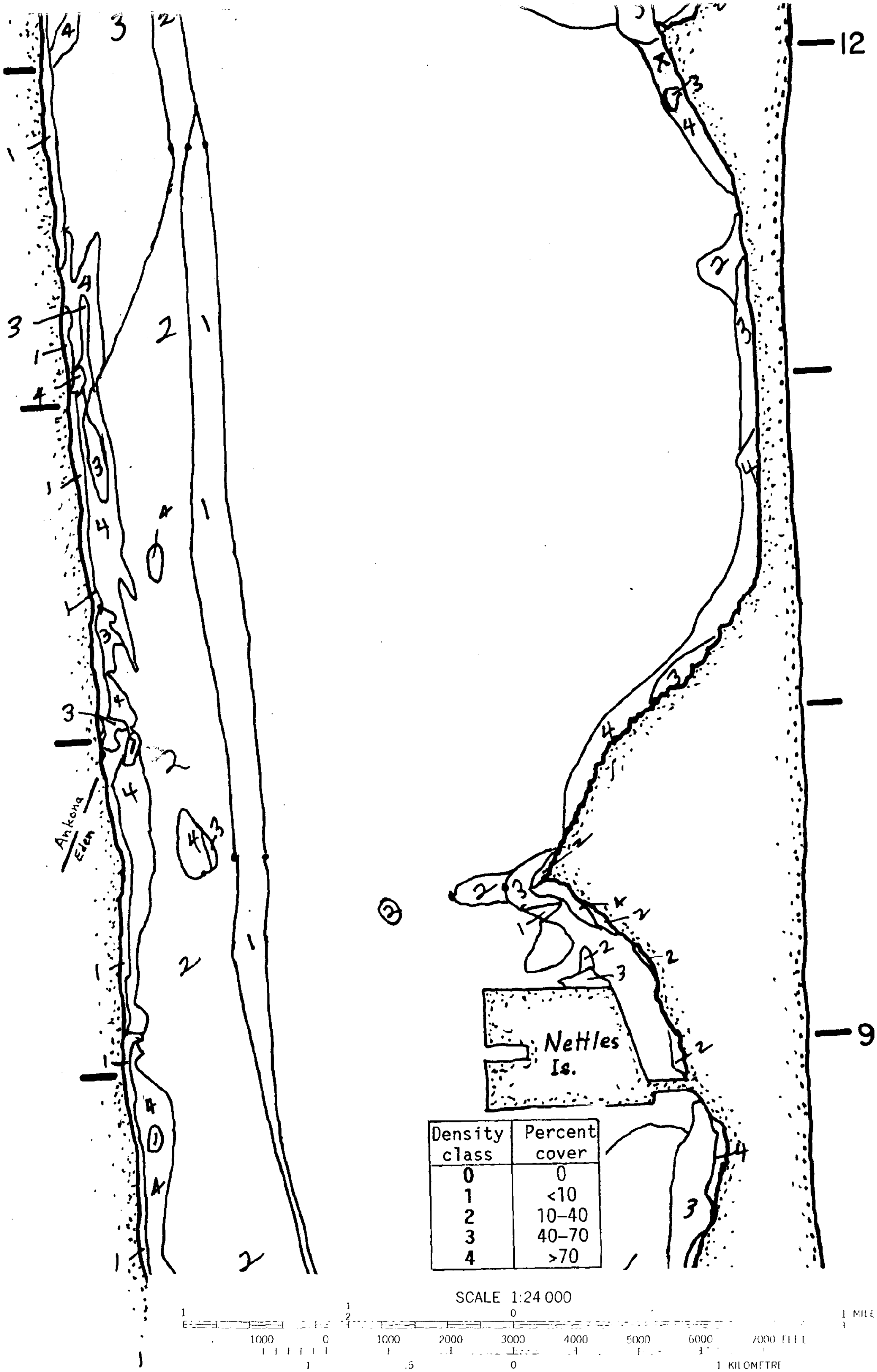
2	10–40
3	40–70
4	>70



Density class	Percent cover
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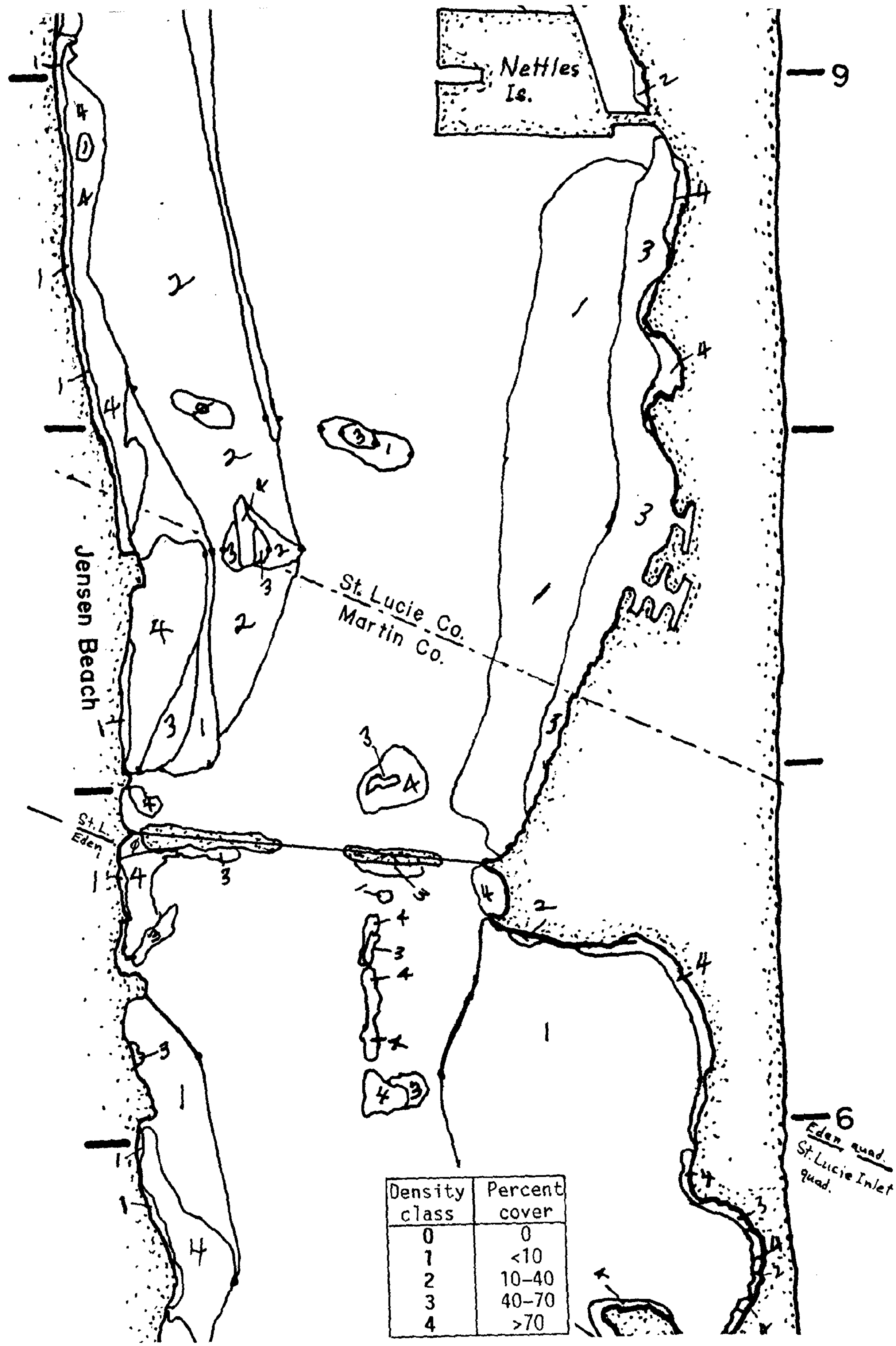
2	10–40
3	40–70
4	>70



Density class	Percent cover
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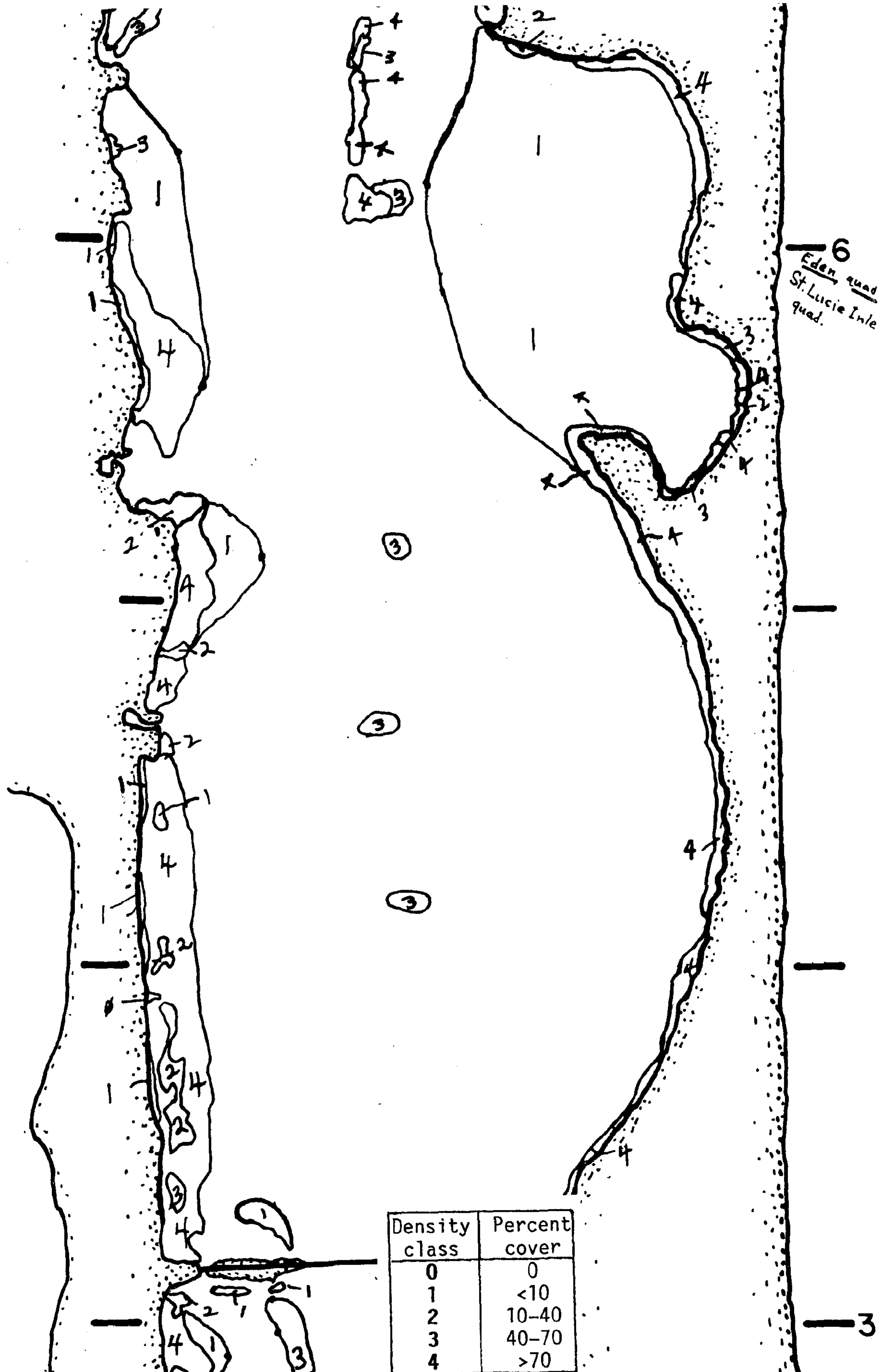
1	<10
2	10–40
3	40–70
4	>70

SCALE 1:24 000

1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETRE



Density class	Percent cover
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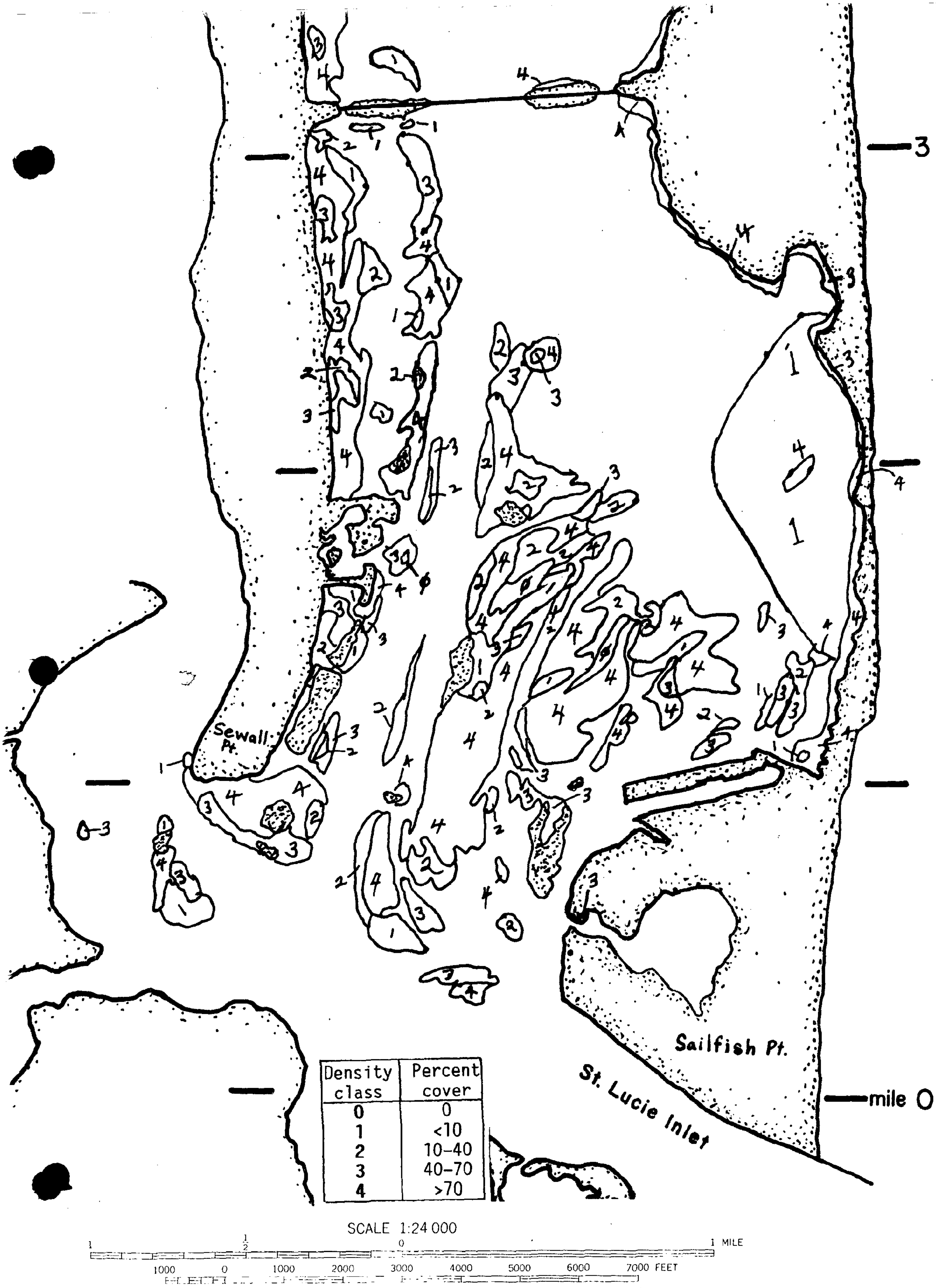
3	40–70
4	>70

SCALE 1:24 000

1 ½ 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETRE


Sewall Pt.
Sailfish Pt.
St. Lucie Inlet
3
mile 0
Density class | Percent cover
0 | 0
1 | <10
2 | 10–40
3 | 40–70
4 | >70
SCALE 1:24 000
1 ½ 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETRE